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GEOLOGIC RECONNAISSANCE
OF PARTS OF THE
WALLA WALLA AND PULLMAN,
WASHINGTON, AND PENDLETON,
OREGON 1° x 2° AMS QUADRANGLES

FOR

U.S. ARMY CORPS OF ENGINEERS
Seattle District
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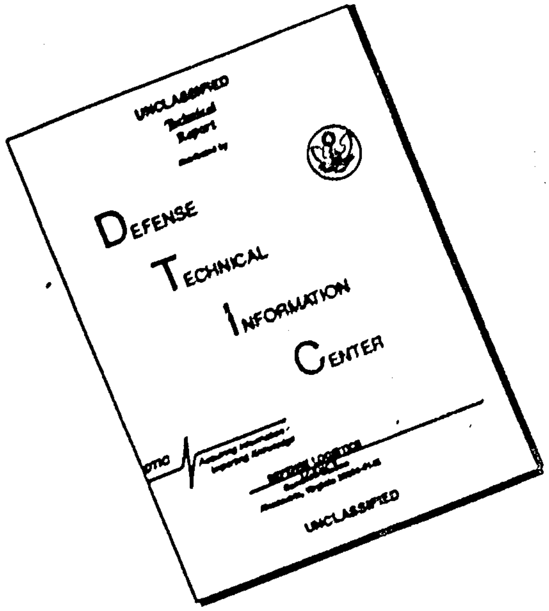

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SUMMARY AND CONCLUSIONS

This investigation was conducted to determine the location and continuity of faulting, the tectonic framework and the evidence for contemporary tectonic activity centering around the Hite Fault System, Wallula Fault system and Service Anticline in portions of southeast Washington and north central Oregon near six U.S. Army Corps of Engineers' dams: Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary and Mill Creek. The study includes a review of previous geologic mapping and lineament studies, a review and analysis of regional tectonics and reconnaissance geological mapping. The areas investigated are shown on Figure 1 and include: 1) a corridor along the lower Snake River; 2) a strip along the Hite Fault in the northwest flank of the Blue Mountains; 3) the Kooskooskie - Mill Creek area east of Walla Walla and 4) the Service Anticline. The study areas include parts of the gently west-dipping Palouse slope, and northwest flank of the Blue Mountains Anticlinorium, the Dalles-Umatilla Syncline, and the Pasco and Walla Walla structural basins.

Most of the area is underlain by bedrock of the Miocene-age Columbia River Basalt. A few windows of pre-Tertiary rock are exposed in deep canyons in the Blue Mountains and along the Snake River. The basalts are partially mantled by younger Plio-Pleistocene continental sediments, by late Pleistocene glaciofluvial deposits of the "Spokane Flood" in the structural lows and by extensive eolian loess elsewhere.

Most faults within the area belong to either the northeast trending Hite Fault System, or the northwest striking Wallula Fault System. The Hite Fault System includes the north-northeast striking Hite Fault and several related north to northeast striking lesser faults. The main Hite Fault extends northeastward along the northwest flank of the Blue Mountains. It enters the study area near Mill Creek and continues northeast to near Pomeroy, where it appears to die out

into a series of small folds. Several newly-found, small north-northeast striking faults north of Pomeroy suggest a continuation of the Hite Fault to near the Snake River. New exposures of the main Hite Fault near and in the Tucannon River demonstrate a significant amount of strike-slip offset (probably right lateral) on the fault, consistent with recent work south of the area (Kienle and others, 1979).

Examination of the Central Ferry Fault and the Mile 72 Fault shows them to also have motions and strikes which are compatible with the interpreted motion of the Hite Fault System. These are both exposed on the Snake River upstream of Little Goose Dam. The north striking Kooskooskie Faults, located a few miles east of Walla Walla, also have motions compatible with the Hite Fault System and appear to connect with it south of the study area.

None of the faults in the Hite Fault System show indications of post-Pleistocene motion. Palouse loess, post-basalt colluvial deposits and Holocene loess pass undisturbed across these faults. Detailed evaluation of post-basalt, pre-Pleistocene movement is not feasible because no sediments of this age other than colluvium, occur along the northwest flank of the Blue Mountains; however, available data indicate that the faults in the Hite System are not capable faults.

The Wallula Fault System includes the west-northwest to northwest striking, right-lateral, strike-slip faults which extend from south of Walla Walla along the south margin of the Pasco and Walla Walla basins, and similar but lesser faults which cut the basins. The master fault in the system is the combined Wallula-Rattlesnake Lineament-Wallula Gap Fault, which locally may cut late Pleistocene Touchet beds and holocene loess (Bingham and others, 1970). A few faults related to or connected to this master fault also cut the Touchet beds and/or younger loess; among them are one of the "Buroker Faults", near Mill Creek Dam, and faults out of the study area, south of Umapine, Oregon.

Several new faults which have trends and offsets similar to, or compatible with, the Wallula Fault System were found during the investigation. The lengths of some previously known, northwest striking faults were extended, and the motions of some were reinterpreted during the study. Extended or reinterpreted faults include the "Buroker Faults" near Walla Walla, the Burr Canyon Fault southwest of Lower Monumental Dam, and the Wallula Gap Fault. New northwest striking faults include the Ben Day Gulch Fault and three additional faults in the "Buroker fault set".

The Service Anticline appears to be unlike other large structures in the area, in that it strikes north-south. The anticline extends from the north flank of the Blue Mountains Anticlinorium, north through Hermiston and Umatilla, Oregon, across the Columbia River and merges with the east-west trending Columbia Hills Anticline. New exposures reveal a major fault zone along the anticlinal axis. Mapping of the minor related faults and striae in the major zone indicate that the Service Anticline is actually a series of short blisterlike anticlines which overlie a left-lateral, strike-slip fault. Minor faulting of Upper Pleistocene gravels (Spokane Flood) occurs north of the Columbia River.

Mapping for this study indicates that faults in the Hite Fault System have not moved in Holocene time. Another recent study indicates they have probably not moved since the Pliocene (Kienle and others, 1979) south of the study area. Thus, faults in, and related to, the Hite Fault System appear to be non-capable and to present no seismic hazard to either the dams along the Snake River or to Mill Creek Dam.

In contrast, several faults in the Wallula Fault System cut post-basalt sediments, and a few cut glaciofluviatile sediments and Holocene loess. This evidence, together with reported ground fissuring during the 1936 State Line Earthquake (Brown, 1937), indicates to us that the Wallula Fault System should be considered to be a capable structure.

The Service Anticline does not appear to deform Pleistocene glaciofluviatile (Spokane Flood) sediments south of the Columbia River. However, apparent faulting of these materials in a new exposure north of the river indicates probable Holocene movement on a fault associated with the Service Anticline, suggesting that the Service Anticline is a capable structure.

The conclusion that the Hite Fault System is older than the Wallula Fault System is important to an understanding of the tectonic development of the area. It implies a change in orientation of the stress field to account for the change, with time, of the orientation of the faults. More important to this analysis, the conclusion implies that only faults with motions compatible with the stress field which produced the Wallula Fault System need to be considered for evaluation of seismic hazard in the area. This is because faults in the Hite Fault System were formed in response to a stress field different from and older than that which caused the motions on faults in the younger Wallula Fault System.

The tectonic model suggested by the new data modifies the tectonic model previously postulated by Glass (1980), Davis (1977) and Lambscher (1977). This new model (Figure 10) attempts to explain only the youngest and/or active tectonic structures, and is thus a neotectonic model. It invokes a maximum compressive stress oriented NNW-SSE to explain the left-lateral motion of the north striking Service Anticline and the right-lateral motion of the west-northwest striking Wallula Fault System. A slight clockwise rotation of the southwest portion of the area is included to account for the change from extension across the Cle Elum-Wallula Lineament (CLEW) in the southeast to compression across it in the northwest.

1. INTRODUCTION

1.1 Purpose of Investigation

This investigation was conducted in support of the U.S. Army Corps of Engineers (Seattle District) Earthquake Risk and Hazard Study for dams on the lower Snake River, McNary Dam on the Columbia River and Mill Creek Dam near Walla Walla, Washington. The purpose of the investigation was to provide data on the location and continuity of faults in the area near these dams, and to provide an interpretation of the age and tectonic framework of faults studied during the investigation. Particular attention was given to faults which could have moved in Holocene or historic time, and, thus, could be considered as capable of producing a seismic event.

Extensive work in the Columbia Plateau in recent years has led to major improvements in understanding of the stratigraphy of the Columbia River Basalt Group, and consequently, to revisions in interpretations of the extent, nature and age of tectonic deformation. Recent investigations have, for example, documented extensive evidence for strike-slip faulting in the Blue Mountains, La Grande Graben and Walla Walla area (see Section 3), and for major thrust faulting in many of the anticlines of the Yakima fold belt. In addition, evidence for young movement (Holocene and late Pleistocene) has been found for some faults in the Walla Walla area (Kienle and others, 1979).

This study has taken advantage of the recent advances in stratigraphic techniques, located many new structures, and used the extensive stratigraphic mapping of Swanson and others (1979a) to re-evaluate tectonic structures in the area of investigation. Presented here are the results of the studies, and our interpretation of the motion, continuity and age of faults.

1.2 Previous Investigations

The earliest geologic studies of the Columbia Plateau and Blue Mountains were conducted by Russell (1893), Smith (1901, 1903),

Merriam (1901) and Williams (1916). Most subsequent investigations were specific to small areas of the region, or concerned petrology of the basalts, origin of the channeled scablands, or construction of the Snake and Columbia River dams. Studies of regional tectonics by Newcomb (1961) and other members of the USGS Water Resources Division (e.g. Hogenson, 1964; Hampton and Brown, 1964) demonstrated the influence of regional-scale structures on the groundwater regime, and ultimately resulted in the first comprehensive tectonic map of the area (Newcomb, 1970).

Newcomb's (1970) tectonic map defined the major structures of the Columbia Plateau: the Walla Walla and Pasco basins, Blue Mountains, Yakima Ridges, Lewiston Monocline, Walla Walla and Hite Fault Systems, La Grande Graben, etc. Subsequent studies have extended some of these structures, refined our knowledge of their motions, origins and ages, and added some lesser structures. However, an integrated picture of the relationships and ages of these major structures is only now beginning to emerge, largely through recent studies for nuclear power plants and the Hanford waste disposal project e.g., WPPSS, 1977; Kienle and Newcomb, 1973; Rockwell, 1979; Glass, 1979; Kienle and others, 1979; and Davis, 1977). The most recent tectonic investigation was by Slemmons and O'Malley (1980), and concentrated on remote sensing analysis of U-2, ERTS, topographic, and aeromagnetic linears.

Several studies have postulated tectonic models for all or part of the Columbia Plateau. At present, the available regional models (Glass, 1980; Laubscher, 1977; Davis, 1977; Rockwell, 1979) are general in scope and deal only with regional structures and seismicity. More elaborate models are available for only limited parts of the Columbia Plateau: Walla Walla-Northern Blue Mountains (Kienle and others, 1979); Wallula Gap Fault (Farooqui, 1979); Yakima Ridges and the Cle Elum-Wallula Lineament (CLEW) (Laubscher, 1977; Kienle and others, 1977); and the Pasco Basin (Rockwell, 1979).

All regional models postulate north-south compression of the areas west of the CLEW, consistent with the north-south shortening of that area by the generally east-west trending folds of the Yakima Ridges. In Newcomb's view (1970), most structures are adequately explained by north-south compression coupled with subsidence of the large basins and uplift of the Cascades and Blue Mountains. However, the models of Glass (1980) and Laubscher (1977) also invoke slight rotation of the area southeast of the CLEW, and predict extensional faulting in the Walla Walla and La Grande basins (Figure 3). The model presented by Glass (1980) is particularly attract , in that it is consistent with detailed mapping by Gehrels and Whit 980) in the La Grande area, by Kienle and others (1977) along the CLEW, by Farooqui (1979) of the Wallula Gap Fault, and by Kienle and others (1979) in the northern Blue Mountains-Walla Walla area. This model represents an improvement over earlier models (e.g. Laubscher, 1977; Davis, 1977) which concentrated on tectonics of the CLEW and areas to the southwest, particularly in that it accomodates the observed dextral slip motion of the Hite Fault and the pull-apart motion of the La Grande Graben (Gehrels and others, 1979; Kienle and others, 1979). The Glass-Laubscher and Newcomb models both predict specific fault motions for the study area, and were partially tested by the field mapping in Phase II. Mapping did not confirm the graben predicted in the Eureka Flats area by the model.

2. STRATIGRAPHY

The four study areas shown on Figure 1 all lie within the Columbia Plateau (Russell, 1893). The Hite Fault, the Kooskooskie-Mill Creek Area and the Service Anticline-Sillusi Butte corridors lie across the northwest margin of the Blue Mountains Anticlinorium and extend from that structure into the structurally lower areas north of it. The Snake River corridor extends from the Palouse slope west and southwest into the Pasco Basin.

The following paragraphs summarize the stratigraphy of the study areas. In this discussion, we have relied on our previous work in the area (Kienle and others, 1979, 1977; Kienle and Newcomb, 1973) as well as work for the Basalt Waste Isolation Program (e.g., Rockwell, 1979).

Geologic units exposed in the area range in age from pre-Tertiary to Holocene (Figure 2). For convenience in map compilation, we have grouped several minor geologic units defined by previous investigations, and, to some extent, subdivided the Columbia River Basalt Group, following the nomenclature of Swanson and others (1979b).

2.1 Pre-Tertiary Rocks (pT)

East of the Hite Fault, on the Snake River and in the Tucannon River drainage area, small scattered exposures of rocks (steptoes) occur that are older than the Columbia River Basalt Group. These steptoes include Granite Point on the Snake River (sec. 13, T13N, R43E), as described by Treasher (1925) and Hopper and Rosenberg (1970), and the outcrops in the Tucannon River drainage (sec. 5, T8N, R41E), which are briefly described by Huntting (1942) and shown on Newcomb (1970).

The lithology of these steptoes is varied. Granite Point is composed of coarse-grained, weakly-foliated adamellite (quartz monzonite) that

displays a distinct mafic segregation and evidence of metasomatism. Along the Tucannon River, the pre-Tertiary outcrops are black and gray chert, green sandstones, greenstones and black to light-colored argillites (Huntting, 1942).

2.2 Columbia River Basalt Group (Ty) and Ellensburg Formation

The Columbia River Basalt Group is exposed throughout the map area, especially in river valleys and in upland areas where the loess cover is eroded. Basalt flows in the area include those of the Saddle Mountains, Wanapum and Grande Ronde Basalt Formations. Generally, the flows form an accordant sequence of flood basalts, with individual flows or groups on flows covering areas of several hundred kilometers. However, intracanyon flows of Saddle Mountains Basalt are exposed in the Snake River Canyon east of Ice Harbor Dam and some Wanapum flows lap out on the flanks of the Blue Mountains and Lewiston Uplift. Locally, sedimentary rocks assigned to the Ellensburg Formation are interbedded with the upper part of the basalt. Detailed stratigraphy of the basalt is shown on Plates 1, 2 and 3 only in areas where it is critical to evaluation of the tectonic structures.

The Grande Ronde Basalt (Tygr) consist of fine-grained, tholeiitic, glassy flows. Locally, these flows are exposed only in the Blue Mountains and in the deeply incised drainages such as the Snake River. An olivine-bearing variant type, likely equivalent to a "high magnesium" type of Beeson and Moran (1979) of the western plateau, is present near the top of the section on the west flank of the Blue Mountains. Flow tops are frequently of the "aa" type with thick (6- to 32-foot [2- to 10-m]) blankets of scoriaceous breccia. Flows and/or flow units are commonly thinner (32 to 65 feet [10 to 20m]) than the average of those in the western part of the plateau (100 feet [30 m]). Both the thickness of the flow-top breccias and the thinness of flow units is consistent with their proximity to the Chief Joseph dike swarm, the probable source for the flows (Taubeneck, 1969; Swanson and others, 1979b).

Flows of normal and reversed magnetic polarity are present within the Grande Ronde Basalt section. In general, the upper part of the section

exposed within the area is of normal polarity (N_2), with reversed flows (R_2) and older flows (N_1 and R_1) only occurring in the lower part (Figure 2), which is exposed in the drainages incised deeply into the Blue Mountains. The upper, normal part of the section is generally about 650 feet (200 m) thick in the Touchet, Tucannon and Walla Walla drainages. Along the Snake River, it pinches out upstream from Lower Granite Dam.

The Vantage Member of the Ellensburg Formation occurs between the Grande Ronde and Wanapum Formations. In the Pasco Basin and areas to the north, the Vantage Member consists of a few inches to several feet of subarkosic sandstone. However, throughout much of the study area the contact between the Grande Ronde and Wanapum is marked by a red-brown saprolitic soil developed on the uppermost Grande Ronde Basalt flow. Locally, the saprolite is a very useful marker horizon, and was informally mapped as "Vantage Member".

The Wanapum Formation (Tyw) is represented by the Eckler Mountain, Frenchman Springs, Roza and Priest Rapids Members. The Dodge flow (Tydo) of the Eckler Mountain Member (Swanson and others, 1979b) overlies the Grande Ronde Basalt. This flow is coarse-grained, includes abundant phenocrysts and glomerocrysts of plagioclase, and contains olivine which has weathered to clay. It is easily recognized by the spheroidal weathering of the outcrops. The type section is located in a roadcut on state Highway 127 east of Dodge, Washington, SW1/4 NE1/4 sec. 16, T12N, R40E, Hay Quadrangle.

The Frenchman Springs Member (Tyfs) overlies the Grande Ronde Basalt and/or the Dodge flow. The Frenchman Springs flows exhibit normal remanant magnetization, are olivine-bearing, have a subdiktytaxitic texture and contain embayed and rounded plagioclase glomerocrysts. Locally, the Frenchman Springs flows can be divided on the basis of the relative abundance of the glomerocrysts. These differences in glomerocryst content persist over large distances in the western

Columbia Plateau (Bentley, personal communication, 1979) and are very useful in establishing an intra-member stratigraphy for the Frenchman Springs flows. However, our observations indicate that no simple, consistent, internal stratigraphy is present throughout the area, and, consequently, differences in glomerocryst abundance in the Frenchman Springs Basalt are only locally useful in establishing stratigraphic offsets across faults in the study area. This appears to be a result of the proximity to a number of Frenchman Springs feeder dikes. Apparently the dikes, which have variable contents of plagioclase glomerocrysts fed a large number of local flow units. Some of these units probably were erupted simultaneously and mixed as they flowed away from the feeders, thus accounting for some lateral variations observed within the flows. Others were apparently of minor extent and cannot be correlated throughout the area. Frenchman Springs dikes are found in the Snake River Canyon. In the northeastern portion of the map area, Frenchman Springs Basalt thins rapidly and pinches out east of the Hite Fault.

The Roza Member (Tyro) overlies the Frenchman Springs Member. The member consists of one or two flows which display a transitional magnetization and are characterized by abundant, large-single plagioclase phenocrysts which are evenly distributed throughout the flow. These phenocrysts make the Roza flow easy to identify in the field and a useful "marker horizon" throughout the map area. Thickness of the Roza flow varies from slightly over 200 feet (60 m) in the northeast part of the area to nearly 300 feet (90 m) in the eastern Pasco Basin. The Roza flows lap out against the Horse Heaven Anticline, and the flanks of the Blue Mountains Anticlinorium.

Roza dikes, first identified by Kienle and Newcomb (1973), occur in the Almota area downstream from Lower Granite Dam. These dikes strike northwest-southeast and extend for several tens of kilometers northwest of the Snake River (Swanson and others, 1975).

The Priest Rapids Member (Typr) overlies the Roza Member. This member is identified by its reversed magnetization and small phenocrysts

of plagioclase and olivine. The member consists of one flow and is found adjacent to the Snake River. The Priest Rapids Member is approximately 200 feet (60 m) thick.

The Saddle Mountains Basalt Formation (Tysm) is represented by intracanyon remnants which outcrop adjacent to the Snake River Canyon east of the Ice Harbor Dam (Plate 2 and 3). West of Ice Harbor Dam, these flows form more continuous units into the Pasco Basin and areas to the south. The Umatilla Member, Pomona Member, Elephant Mountain Member, Ice Harbor Member, and Lower Monumental Member constitute the Saddle Mountains Basalt Formation within the study area.

The Umatilla Member (Tyum) is easily recognized as it is one of the most fine-grained of the Columbia River Basalts. This member includes two flow units at its type locality west of McNary Dam on the north shore of the Columbia River (SE1/4 SE1/4 SE1/4 sec. 4, T5N, R28E0). The Umatilla Member is approximately 330 feet (100 m) thick near Wallula Gap, Washington. This unit, although easy to identify in outcrop because of the presence of flow banding and normal magnetic polarity (Rietman, 1966), is not a useful stratigraphic unit east of the junction of the Snake and Columbia Rivers and west of the Blue Mountain Uplift in southeastern Washington, as no Umatilla outcrops have yet been found in that area. In this report the basalt flow mapped as the Wilber Creek Member by Swanson and others (1979b) is included in the Umatilla Member.

The Selah Member of the Ellensburg Formation overlies the Umatilla Member of the Saddle Mountains Basalt. Throughout much of the area the Selah consists of a few inches of tuffaceous silt. However, in the central Pasco Basin it reaches a thickness of over 70 feet (21 m). South of the Columbia Hills Anticline (Figure 3) the Selah occupies a large basin extending from east of McNary Dam downstream nearly to John Day Dam. Thicknesses in excess of 300 feet (90 m) occur in the central portions of the basin between Hermiston and Arlington, Oregon (Kienle and Newcomb, 1973). In its thicker parts, the Selah consists of volcaniclastic materials interbedded with tuffaceous lacustrine and fluvial silts and sands.

The Pomona Member (Typo) is represented by many scattered intracanyon remnants adjacent to the Snake River from Asotin, Washington, (T10N, R46E) to the Ice Harbor Dam. This member overlies the Umatilla and Wilbur Creek Members and the Selah Member of the Ellensburg Formation within the Pasco Basin, and other basalt members (e.g., Esquatzel Member) adjacent to the Snake River south of the Horse Heaven Anticline the Pomona overlies 20 feet to 300 feet of Seleh Member. It underlies the Elephant Mountain Member. The Pomona is generally about 130 feet (40 m) thick within the Pasco Basin; however, the preserved remnant at the mouth of the Tucannon River is 360 feet (110 m) thick (Swanson and others, 1979b). This member is characterized by its reversed magnetization, and the abundance of small, lath-shaped phenocrysts of plagioclase. Rare large phenocrysts of plagioclase, pyroxene and olivine measuring up to 10 cm are found in some outcrops.

The Rattlesnake Ridge Member of the Ellensberg Formation overlies the Pomona Member of the Saddle Mountains Basalt. The thickness varies from a few inches to over 40 feet (12 m) with the thickest portions occuring in the central Pasco Basin. The Rattlesnake Ridge Member is predominantly weathered tuff with occasional thin layers of fluvial silt and clay.

The Elephant Mountain Member (Tyem) is a generally fine-grained flow which is characterized by transitional magnetization. This member is 100 feet (30 m) thick and covers an extensive part of the Columbia Plateau west of the Ice Harbor Dam; however, east of the dam, the flow occurs as remnants up to 330 feet (100 m) thick along the Snake River (Swanson and others, 1979b).

The Ice Harbor Member (Tyih) occurs in a limited area extending north-northwest from the Washington-Oregon border centered around Ice Harbor Dam on the Snake River. The member contains two informal units: the basalt of Martindale and the basalts of Goose Island. The Martindale displays reversed magnetic polarity (Helz, 1973), is about 50 feet

(15 m) thick, and contains phenocrysts and glomerocrysts of clinopyroxene, plagioclase and olivine. It appears to be the most extensive of the Ice Harbor flows (Swanson and others, 1979b). The Goose Island overlies the Martindale and is also about 50 feet (15 m) thick. This flow contains both basalt and tephra, and is characterized by phenocrysts of plagioclase, magnetite and olivine. The basalt of Goose Island has transitional to normal magnetic polarity. Many dikes of the Ice Harbor Member are located in the "belt of major outcrop" (Swanson and others, 1975, 1977, and 1979b), near Ice Harbor Dam.

The Lower Monumental Member (Tylm) is found adjacent to the Snake River in Washington from east of Lower Monumental Dam to Asotin, Washington (T10N, R46E). Although stratigraphic relationships for this member are not definitive, potassium-argon age dating by McKee and others, (1977) indicates an age of about 6.5 m.y. Therefore, this is the youngest known member of the Columbia River Basalt Group. The Lower Monumental Member is characterized by its aphyric texture, normal magnetic polarity, and the presence of microphenocrysts of olivine (Swanson and others, 1979b). The member, represented by remnant flows along the present course of the Snake River, is generally 100 feet (30 m) thick.

2.3 Plio-Pleistocene Sediments (QTs)

This unit includes all sedimentary deposits whiah overlie the Columbia River Basalt Group and underlie the Pleistocene glaciofluviatile deposits. This includes the "old gravel and clay" (Qcg) and Ringold Formation (Qr) of Newcomb (1965) in the Walla Walla River Basin. The Ringold Formation (Trs, Trc, and Trf) of Rockwell (1979), (Tr) of Rigby and Othberg (1979), is "exposed in a quarry in SE1/4 SW1/4, sec. 11, T9N, R32E and E1/4 NE1/4 sec. 6, T9N, R33E".

In general, these sedimentary materials are correlative with, or contiguous with, the upper part (post-basalt) of the Ellensberg Formation, Ringold Formations in southern Washington, and the Dalles Formation in Oregon (Newcomb, 1971). They range from coarse- to

fine-grained, dirty gravel fans which were shed from the rising Blue Mountains, to fine-grained, silty-clayey lake beds which were deposited in local basins that formed behind growing late Tertiary structures.

2.4 Touchet Beds (Qt) and Glaciofluviatile Deposits (Qgf)

The Touchet beds (Flint, 1938) are the slackwater facies of the deposits of the late Pleistocene "Spokane Floods". They contain rhythmically-bedded silts and sands, and were deposited in low-energy environments. Clastic dikes, thought to result from dewatering during draining of the flood-induced lakes, are common. As mapped during this study, they include the Touchet beds of Flint (1938) and Newcomb (1965), and the catastrophic flood slackwater sediments (Qfs) of Rigby and Othberg (1979), and the Touchet beds (Qht) of Rockwell (1979). Work by Waitt (1978) suggests that the Touchet beds range in age from 10,000 years to 13,000 years.

The coarse-grained, torrential flood deposits which formed during the "Spokane Floods" commonly form large, bouldery gravel bars along the main drainages and coulees. These deposits are composed of clasts of basalt, granite, quartzite, diorite, and porphyry. As mapped, this unit includes the Qgf of Newcomb (1965) and Hogenson (1965), as well as Pasco Gravels (Qlp) of Rockwell (1979), and catastrophic flood gravels (Qfg) of Rigby and Othberg (1979). The gravels occur under or interbedded with the Touchet beds and similar to the Touchet beds range in age from 10,000 years to 13,000 years (Waitt, 1978).

2.5 Quaternary and Holocene Alluvium (Qa)

Alluvial deposits of inferred late Pleistocene to Holocene age occur in drainages throughout the areas. These deposits include fluvial sand, silt, and gravel (Qya, Quv, and Qoa of Newcomb, 1965), talus, local lacustrine, paludal and alluvial fan deposits (Qaf and Qafo of Rigby and Othberg, 1979). Locally, some smaller areas of fine-grained glaciofluviatile deposits are also included.

2.6 Loess (Ql)

Loess, eolian silt and fine sand mantle most of the map area in varying thicknesses. The loess is thickest in central and southeastern Washington; however, the unit thins and becomes finer-grained further from the ancestral Columbia floodplain.

At least two distinct ages of loess are included on Plates 1, 2 and 3, and Figure 2. These are the largely pre-glacial Palouse loess (Newcomb, 1961, 1965) and a younger, post-glacial loess derived principally from eolian reworking of the Touchet beds.

2.7 Dune Sand (Qd)

Eolian dunes of sand-sized particles of quartz and basalt are found adjacent to the Snake River west of the Snake River Station (sec. 34, T11N, R33E). These active and stabilized dunes are the youngest known deposits within the map area. This deposit includes dune sand (Qd) of Rigby and Othberg (1979), active sand dunes (Qda) and stabilized sand dunes (Qds) of Rockwell (1979).

3. STRUCTURES

Although the areas of investigation (Figure 1) are all underlain by flows of the Columbia River Basalt, several distinct structural terrains occur (Figure 3). These include the usually gentle, but internally complex, Blue Mountains Anticlinorium, parts of the Pasco and Walla Walla structural basins, and the generally homoclinal Palouse slope. Superimposed upon these master structures are the lesser folds of the southern part of the Yakima fold belt; the Rattlesnake-Wallula structure; the Horse Heaven Anticline; the Swale Creek-Glade Creek Syncline; the Columbia hills Anticline; the Dalles-Umatilla Syncline; and the Service Anticline. Major faulting appears to be restricted to areas near the intersections of the different terrains or major structures. The Hite Fault separates the Blue Mountains from basins to the northwest, while the Wallula Fault separates the Horse Heaven and Rattlesnake structures from the Walla Walla and Pasco Basins, respectively.

3.1 Regional Folds

3.1.1 Pasco and Walla Walla Structural Basins

The Pasco and Walla Walla Basins are structurally the lowest areas in the Columbia Plateau. They are also the deepest portions of a broad structural low which trends approximately northwest-southeast for nearly 100 miles (160 km) along the east side of the Cle Elum-Wallula Lineament (Kienle and others, 1977) (Figure 3). The two basins, although structurally part of the same low, are separated from each other by the Divide Anticline (Newcomb, 1965), and from structural highs to the southwest by the Wallula Fault and the Rattlesnake-Wallula Lineament. To the northeast, both basins merge into the Palouse slope across a series of low-amplitude, northwest-striking monoclines, anticlines and synclines. The northern and northwestern margins of the low are formed by the Saddle Mountains Anticline and the Cle Elum-Wallula Lineament, respectively (Kienle and others, 1977).

In the southeastern Pasco Basin and in the Walla Walla Basin, i.e., the areas included in this study, fairly thick accumulations of post-basalt sediments are present which mantle structures in the basalt (Plate 2). However, locally, and particularly along the southwest margin, faults of the Wallula system have offset upper Pleistocene flood deposits (Section 3.2.2).

3.1.2 Palouse Slope

The Palouse slope is a generally southwest-dipping homocline which extends from the eastern and northeastern margins of the Columbia Plateau to the Pasco-Walla Walla structural low on the southwest and the Blue Mountains on the south and southeast. Within the study area, the Palouse slope generally dips 0.5° to 1° or less into the Pasco and Walla Walla basins, except along the north flank of the Blue Mountains between Walla Walla and Pomeroy, where dips generally swing to the northwest towards the Snake River. Only minor structures disturb the gentle basinward descent of the basalts. These include a series of small, low-amplitude, anticlines, synclines and monoclines which generally strike northwest. The most prominent of these folds are exposed along the Snake River upstream from Little Goose Dam, near Votaw siding (northwest of Eureka between Lower Monumental and Ice Harbor dams), and downstream of Ice Harbor Dam (Plate 2).

These northwest-striking folds generally have amplitudes between 50 and 150 feet (15 and 43 m), widths from 1/2 to 1-1/2 miles (0.8 to 2 km), and lengths from a few miles to over 20 miles (32 km). They are usually tilted to the southwest, so their effect is to break the Palouse slope into a series of small, steplike wrinkles. Much of the basinward descent of the basalt appears to occur across these folds. The best example of this folding is the west-facing monocline west of Votaw siding (T10N, R33E). East of this monocline, referred to as the "Votaw Monocline", the Pomona and Elephant Mountain flows occur as intracanyon flows. To the west they both occur as sheet or flood flows. Thus, the "Votaw Monocline" is part of the eastern margin of the structural low in which these two flows accumulated.

3.1.3 Blue Mountains Anticlinorium

The Blue Mountains Anticlinorium is a large, generally box-shaped fold which extends east-northeast from the Cascade Range across north central Oregon to south of Pendleton, where it turns north-northeast. It continues this trend into the study area, to the Touchet drainage (T7N, R40E), where it turns once again onto a generally east-west trend. Both major changes in trend of the anticlinorium occur near the Hite Fault System. Indeed, the Hite Fault System forms a major part of the western hinge of the box fold where the fold and faults parallel one another (Kienle and others, 1979). Structural relief on the anticlinorium is over 5,000 feet (1500 m) east of Walla Walla, measured on the elevation of the Vantage Horizon. The western flank of the north-northeast trending part of the Blue Mountains Anticlinorium extends into the southeast portion of the study area. Several small folds and faults (Plate 3), most of which appear related to the Hite Fault, cross this portion of the structure (refer to Section 3.2.1). The axis of the east-west trending portion of the structure lies largely south of the study area; only the gentle north flank extends into the Tucannon River-Pataha Flat area (Tps. 9, 10 and 11N, Rns. 41, 42 and 43E). As with the north-northeast trending portion, the northern flank of the Blue Mountains Anticlinorium is crossed by a series of small monoclines and a few faults (Plate 3) which appear related to the Hite Fault.

3.1.4 Horse Heaven Anticline

The Horse Heaven Anticline is the largest anticlinal structure in the southern part of the Yakima Ridges (or Yakima Fold Belt; Kienle and others, 1977; Newcomb, 1970). The fold rises from the Blue Mountains' north flank, south of the study area, and continues north-northwest into the area near Wallula Gap (Figure 2). It continues this trend to near Benton City, Washington, where it turns onto a generally westerly trend and continues westward to the Cascade Mountains (Newcomb, 1970). Within the area of investigation (Plate 2), the Horse Heaven Anticline is assymetrical with a gentle 0.5° to 1° south flank and a steeper 3° to 5° north flank. The north flank is cut by faults which are apparently part of the Wallula Fault System (Newcomb, 1965; Farooqui, 1979). These

faults occur along, and parallel to, the Rattlesnake Wallula Lineament (Section 3.2.2.3) which merges into the north flank of the Horse Heaven Anticline just west of Wallula Gap. South of Umapine and Touchet (T5N, R53 and 34E), the amplitude of the fold is about 1,300 feet (390 m). At Wallula Gap, it is less than about 1,000 feet (300 m), while west of Wallula Gap, the anticline becomes more complex and its amplitude increases to over 1,600 feet (480 m). The fact that Wallula Gap occurs at a structural low in the Horse Heaven Anticline is consistant with structural control of the course of the Columbia River. The lowest structural elevation of the Horse Heaven Anticline occurs, however, at its eastern end, south of the study area. There, the maximum elevation of the top of the Columbia River Basalt is about 1,600 feet (480 m) above sea level, as opposed to about 1,730 feet (520 m) at Wallula Gap. Kienle and others (1979) suggest that this may indicate subsidence of the east end of the structure since establishment of the present course of the Columbia River through Wallula Gap. This interpretation is consistent with the apparent movements along young faults in the Wallula Fault System, which trend west-northwest along the Horse Heaven Anticline's north flank near Milton Freewater, south of the study area.

3.2 Regional Fault Systems

3.2.1 Hite Fault System

The Hite Fault System consists of a set of at least five major north-northeast striking faults (Kienle and others, 1979). The system extends from east of Pendleton, Oregon, along the northeast flank of the Blue Mountains into southeast Washington. The largest of the faults is the Tom Hite Fault, generally referred to simply as the Hite Fault. It is the easternmost large fault in the system which bears its name, and the only major fault in the system which extends into the project area (Figure 1), near longitude 118°W, latitude 46°N (Plates 2 and 3).

South of the project area, in the Mill Creek drainage, the Hite Fault is well exposed as a complex, major zone of faults whose most

recent movement has been interpreted as right-lateral, strike-slip (Kienle and others, 1979; Kienle and Hamill, 1980). Within the study area, the Hite Fault is less well exposed, but it is relatively easy to follow because of the generally large offset across it and its distinct topographic expression.

From the south margin of the study area (Plate 3), near Paradise Ridge, (T6N, R39E) northeastward to the Tucannon drainage (T10N, R41E), the Hite Fault is expressed topographically as a series of aligned drainages and notches in ridges and spurs. Within this stretch, the fault generally consists of a conspicuous main strand 300 to 1,000 feet (100 to 300 m) wide, and one or more parallel or sub-parallel lesser strands which vary from less than 3 feet (1 m) to at least 30 feet (10 m) across. North of the Tucannon River (T10N-T11N boundary, R41E) the Hite Fault becomes a much less prominent topographic feature, largely because of the thick cover of loess, but also because of a decrease in apparent offset across the structure.

From Eckler Mountain (T9N, R40E) to the south, vertical offset across the zone is about 600 to 650 feet (180 to 200 m) with the northwest side down. Northeast of Eckler Mountain, the vertical component decreases to about 200 feet (60 m) at the Tucannon River. North of the Tucannon River, the apparent vertical offset of the fault decreases, although there is evidence to suggest that vertical offset of the Grande Ronde flows is larger than the few tens of meters expressed in the overlying Wanapum flows, as discussed below.

The Hite Fault System (Plate 3) is paralleled by west-facing drag folds, a geometry consistent with the west-side-down vertical offset. These drag folds are well-exposed where the fault crosses the Touchet and Tucannon Rivers (Plate 3). Together the drag folds and the vertical offset of the fault have a structural relief of about 980 feet (300 m) in the south part of the area and about 600 feet (180 m) south of the Tucannon River, based on the difference in elevation of the top of the Grande Ronde Basalt (Vantage horizon) across the fault zone and associated folds.

The best exposures of the Hite Fault are along the Tucannon River on the east canyon wall (NE 1/4 sec. 16, T10N, R41E) and about 1-1/3 miles (2 km) to the northeast along Blind Grade Road (NW 1/2 sec. 10, T10N, R41E). There the main Hite Fault Zone is bounded by two parallel gouge zones about 600 feet (180 m) apart. The western gouge zone dips approximately 80°E and averages about 20 feet (6 m) in width. It consists of about 19 feet (5.7 m) of silica-cemented gray breccia and about 1 foot (0.3 m) of yellow-brown clay-silt gouge on its west margin. The clay-silt gouge has well-developed striae which rake 10°N. At the Tucannon exposures, this western margin strikes N30°E, while to the north it curves gently northward to a N21°E strike on Blind Grade Road.

The east boundary of the zone is less well defined, apparently consisting of shattered basalt cut by an anastamosing network of east dipping shears which strike between N50°E and N30°E, and dip between 55°E and 80°E. Shears along the east boundary which have strikes closest to that of the overall zone (N21°E) have the steepest dips (80°E) and striae which are close to horizontal (rake 10°N); shears most divergent have the shallowest dips (as low as 55°SE) and the steepest raking striae (up to 40°N).

A small thrust fault (not shown on map) dipping 40°N and striking approximately east-west also cuts the east margin of the Hite Fault on Blind Grade Road. Although offset is only a few feet, the presence of this small thrust is consistent with the other features described above which suggest strike-slip motion.

North of the Tucannon River-Blind Grade Road area exposures, the Hite Fault Zone is largely covered by thick deposits of loess and colluvium. In Linville Gulch (center sec. 3, T10N, R41E), the fault is inferred to pass through a notch between exposures of Grande Ronde and Dodge basalts located about 350 feet (110 m) apart. Offset of the Dodge flow of the Frenchman Springs Member of the Wanapum Basalt appears

to be about 160 feet (50 m) down to the west, as compared to about 300 feet (90 m) approximately 1-1/3 miles (2 km) south. Together with the apparent narrowing of the fault zone from about 600 feet (180 m) at Blind Grade Road to about 350 feet (100 m), this suggests a rapid diminution of total movement on the fault from the Tucannon River to the north. Indeed, at Pataha Flat, about 3-1/2 miles (5.6 km) north-northeast of Linville Gulch, the unfaulted Roza flow passes across the trend of the Hite Fault.

Although no continuation of the Hite Fault was found through Pataha Flat, two faults approximately on trend with the Hite Fault were found north of Pomeroy in Tps12 and 13N, R42E. Both of these faults cut Grande Ronde and lower Wanapum (Frenchman Springs) flows, but are not known to cut the Roza flow. The first and southernmost of these faults extends at least from the west end of the Ben Day Gulch Fault (NE 1/4 sec. 20, T12N, R42E) on a N10°E strike, to Meadow Creek, 2 miles (3 km) to the north. It is well exposed in cuts on the Gould City Road (SE corner SW 1/4 sec. 9, T12N, R42E). The fault gouge consists of about 15 to 17 feet (4.5 to 5.2 m) of indurated, brown, basalt breccia in a brown-orange clayey silt matrix. Sheared and shattered Grande Ronde Basalt extends at least 30 feet (9 m) on both sides of the zone which, at this exposure, strikes approximately N5°E to N10°E. Horizontal striae occur at both contacts between the gouge and the sheared basalt. No significant vertical offset of the basalt was observed, consistent with the horizontal striae. The zone is cut by several small vertical shears which strike N50°W.

The second, northern fault extends from at least Meadow Creek (NE 1/4 sec. 8, T12N, R42E) northward to South Deadman Creek, and is inferred to extend along a photolinear striking N15°E to the northeast of Gould City (NW corner sec. 21, T13N, R42E), a distance of about 3-1/2 miles (6 km). This fault is also exposed in cuts along the Gould City Road (SE 1/4 sec. 32, T13N, R42E). Where exposed, it is a shear zone striking N5°E, which dips 86°E to 88°E. The zone consists

Page 20 intentionally omitted.

of 2-1/2 feet (3/4 m) of cemented red-brown breccia, with about 1 foot (1/3 m) of coarse, indurated, rubbly, basalt breccia in a clay-silt matrix on the west side of the zone. Well-developed horizontal striae and grooves are exposed in the west wall of the fault. About 1 mile (1.6 km) along the fault trend to the south, a small, east-west striking thrust, dipping 18°N, is exposed cutting the Frenchman Springs flows (NW 1/4 SW 1/4 sec. 4, T12N, R42E). The orientation and slip of this small zone are consistent with strike-slip motion on the adjacent fault striking N10°W.

3.2.1.1 Other Structures Related to the Hite Fault. Several features were mapped which appear to be related to the Hite Fault. These include two parallel monoclines which extend north-northeast along the Hite Fault trend north of Tatman Gulch (sec. 23, T11N, R41E) to near Pomeroy. Across the eastern monocline, which is an antiform, the dip of the Roza flow increases from near-horizontal to about 1-1/2° to 2°W. Across the western, synform monocline, dips decrease again to near-horizontal. Net structural relief is about 100 feet (30 m) on the surface of the Roza flow.

Also apparently related to the Hite Fault is a feature referred to as the "Pataha synform". It consists of a tight, northeast-striking syncline, which is exposed at Pataha in cuts on Bell Plain Road (SW1/4 sec. 35, T12N, R42E) and to the south in Benjamin Gulch (S1/2 sec. 8, T11N, R42E), and which opens southward into a northwest-facing monocline as it nears the north end of the Hite Fault. At Pataha, the fold strikes about N25°E; the west flank dips 13°SE, while the east flank dips at least 20°NW. At Benjamin Gulch, the west flank of the "Pataha synform" dips about 8° SE, while the east flank dips only 2° NW. South of Benjamin Gulch, dips on the east flank flatten to horizontal or to a slight westward dip near the Hite Fault.

Another feature related to the Hite Fault is the Linville Gulch Fault, which appears to be a north-northwest striking splay of the Hite Fault. It is inferred to extend along Linville Gulch (T11N, R41E)

for a distance of approximately 5 miles (8 km). The elevation of the base of the Dodge flow appears to be about 80 to 100 feet (25 to 30 m) higher west of the gulch than to the east (sec. 33 and 34, T11N, R41E). A small gouge zone, possibly related to the fault, is exposed along the Linville Gulch Road about 2 miles (3.2 km) north-northeast of the Hite Fault (NE 1/4, SE 1/4 sec. 28, T11N, R41E). The gouge zone trends approximately N40°W and consists of 8 to 10 feet (2-1/2 to 3 m) of loose basalt breccia in a clay silt matrix. Poor exposures did not permit determination of the apparent sense of offset.

The Linville Gulch Fault was previously inferred to extend north-northeast to the Central Ferry Fault (T13N, R40E) by Kienle and Newcomb (1973). However, more detailed work conducted for this study shows that the Linville Gulch Fault must stop south of Pataha Creek, where flows can be traced unbroken across its projected trend.

Faulting along the Snake River (T14N, R42E) downstream from Lower Granite Dam was previously interpreted to be an extension of the Hite Fault (Kienle and Newcomb, 1973). This interpretation was based mainly on prominent north-northeast trending topographic linears, which continue between Illia and Gould City, and the pinch out of the Frenchman Springs Member in the general location of these linears. Mapping during this study, however, suggests that faulting near Illia (Tps 13 and 14N, R42E) trends northwest and is related to the other small northwest-trending faults in the study area, as discussed in Section 3.2.2.6.

3.2.1.2 Age and Offset of the Hite Fault. Because of the well-expessed drag folds, large vertical offset and lack of good outcrops of the fault zone itself, the Hite Fault has previously been interpreted as a down-to-the-west, normal fault (e.g. Newcomb, 1970, 1965; Swanson and others, 1977). However, as described above, more detailed work, examination of new borrow and road cuts along the fault zone within the study area, and mapping to the southwest of the study area (Kienle and others, 1979), document significant strike-slip

on the Hite Fault between its southern terminus east of Pendleton, Oregon, and the Tucannon River area. Observations along the fault suggested to Kienle and others (1979) that dextral slip was the most likely sense of offset. However, data developed by Davis and others (personal communication, 1980) east of Pendleton, Oregon, may be more consistent with left-lateral offset.

Age of the Hite Fault is also problematic. Although young alluvium, the Palouse Formation and colluvium are not deformed by the fault, pre-Palouse sediments whose age can be firmly fixed have not yet been found across its trend. South of the area, the Hite Fault appears to be older than faults of the Wallula Fault System.

Lack of faulting of the Roza flow at Pataha Flat was interpreted by Newcomb (1970) as indicating that the Hite Fault ended at Tatman Gulch, south of Pataha Flat. However, Kienle and Newcomb (1973) later found evidence for faulting on trend with the Hite Fault, north of Pataha Flat. They interpreted the lack of faulting of the Roza flow at Pataha Flat to show that the youngest movement of the Hite Fault was of pre-Roza age. Subsequently, Swanson and others (1977) found offset of the Roza flow south of the Tucannon River in the Cahill Mountain area (T9N, R40E) and revived the earlier interpretation that the Hite Fault ends south of Pataha Flat, with the additional refinement of two small monoclines. Thus, their mapping suggests that deformation north of Pataha Flat along the Hite Fault trend could be associated with the dying out of a normal fault into a west-facing monocline.

Two new lines of evidence are, however, at odds with this normal-fault interpretation. First is the abundant evidence for strike-slip motion on the Hite Fault, both in and south of the study area. This evidence includes not only subhorizontal to horizontal slickensides and striae, but the presence of conjugate shears located within and extending from the Hite Fault Zone (Kienle and others, 1979). Second is the local presence of small, generally east-west trending

normal and thrust faults in, and emergent from, the Hite Fault Zone. These faults show local elements of extension and compression parallel to the main zone, and are similar to features found on many large strike-slip faults elsewhere.

3.2.1.3 Central Ferry Fault. The Central Ferry Fault, as defined here, extends from a quarry east-northeast of Dodge (SW 1/4, SE 1/4 sec. 10, T12N, R40E) northward to the Snake River at Central Ferry (NE 1/4 sec. 9, T13N, R40E), and probably extends across the Snake River and under glaciofluvial deposits for a total distance of about 10 miles (16 km). The fault is expressed as a linear topographic depression and as notches in drainages and ridges. It is exposed in roadcuts in lower Deadman Creek, along the new state Highway 127, and in the above-mentioned rock quarry near Dodge, where it is intersected by another fault which strikes N50°W. The measured strike of the gouge zone in outcrops ranged from N5°W to N15°W. Well-exposed striae rake from horizontal to 11° N. The east side of the fault is down at Central Ferry, which, together with the striae and low dips, indicates a left-lateral sense of movement. Previous reconnaissance mapping (Kienle and Newcomb, 1973) had inferred a connection between the fault exposed at Central Ferry and the Linville Gulch Fault (Section 3.2.1.1); however, the present study documented that such a connection does not exist.

Gouge and shear zones observed along the fault are variable in both width and degree of brecciation. At the exposure in the quarry near Dodge, the fault consists of several small vertical shears, 2 to 10 inches (5 to 25 cm) in width, which cut shattered and jointed Dodge flow in the north face of the pit. The fault is cut by an intersecting N50°W fault with 2-1/2 to 3 feet (0.5 to 1 m) of gouge. The small shears lie along a linear north-south trending depression which continues toward Deadman Creek and allows a tentative connection of this exposure with the northern exposures of the Central Ferry Fault.

A linear mound or possible reverse slope scarp trending N5°W was observed in a tilled field of loess about 1 mile northeast of Housner

(center sec. 22, T12N, R40E). This unusual feature was observed on a southern extension of this fault alignment in the south wall of Pataha Valley which had not been noted in the photolineament surveys (Slemmons and O'Malley, 1979 and Rockwell, 1979); however, it was clearly expressed in low-sun-angle conditions during field work. This scarp could be a result of young deformation, or a result of the loess following the buried basalt surface. If it is a result of deformation of the loess, it could indicate deformation more recent than that observed elsewhere along the alignment. The reverse slope scarp is approximately 200 yards (180 m) long and 3 to 5 feet (1 to 1.5 m) in height; it cross cuts the cultivated slope obliquely. Due to the lack of bedrock exposure and private land access restrictions, no further study was possible within the scope of this investigation.

In the northern exposures of the Central Ferry Fault, breccia zones were larger and more obviously related to a through-going fault. Along state Highway 126 (NE 1/4 NW 1/4 sec. 27, T13N, R40E) breccia zones 14 to 16 inches (35 to 40 cm) wide are exposed. They strike N 10°W, dip approximately 85°W and exhibit horizontal striae. Further north and lower in the Meadow Creek drainage (NW 1/4 sec. 22), the fault consists of a vertical, 4-1/2 to 5 foot (1-1/3 to 1-1/2 m) wide brecciated zone which strikes N 10°W to N 15°W. The fault is vertical and has well-developed striae raking 8°N. A few inches of fine, yellow, clay-silt gouge are found in the zone margins; a coarse basalt breccia forms the center. At this locality, no stratigraphic offset could be determined within the Frenchman Springs Basalt.

Near the confluence of Deadman Creek with the backwaters of Little Goose Dam (NE 1/4 NE 1/4 sec. 16, T13N), the Central Ferry Fault is exposed in a roadcut on state Highway 127. It consists of an 18-foot (5-m)-wide gouge and breccia zone dipping 86°W, very similar in nature to those described above. This zone is traceable northward along a strike of N 16°W at the southern bank of the Snake

River. There, it has an apparent 25-foot (8-m) vertical offset, with the east side down. At the river, the fault zone is concealed beneath glaciofluvial and alluvial deposits, which fill an erosional notch in the basalt exposure. The fault apparently dies out beneath glaciofluvial deposits that fill a pre-Spokane Flood channel north of the Snake River.

Although the Central Ferry Fault is shown as a single zone on Plate 3, it may be composed of several short, parallel, en echelon segments. Non-aligned portions of this fault along strike have orientations which are slightly more westerly than that of the overall zone. The segment exposed between Deadman Creek and the Snake River appears to be the major fault in the system, and appears to be a controlling element of the Meadow Creek drainage for a distance of about 2 miles (3 km). No exposure of southern end of this segment of the fault is apparent in the north-sloping valley wall; a persistent, but thin loess cover conceals the possible extension. Alternatively, this segment may die out north of Meadow Creek, with motion on the fault translated through to the smaller, subparallel fault segments exposed to the south-southwest. This pattern appears to continue throughout the extent of the fault system, and is consistent with the left-lateral slip inferred from outcrops just south of the Snake River. This left-lateral slippage on the system, along with the translational, en echelon pattern, would suggest a north-south to northeast-northwest axis of maximum compressional stress.

Loess, alluvium and glaciofluvial deposits observed overlying the individual fault exposures do not exhibit any offset or post-Pliocene movement. However, units overlying the basalt were not abundant or well exposed; therefore, a definitive age for the last movement cannot be firmly established. The linear mound observed in Pataha Valley presents an unexplained exposure, and, therefore, is considered a good candidate area to help solve this problem.

3.2.1.4 Mile 72 Fault. Approximately 1.6 miles (2.5 km) upstream from Little Goose Dam (SE corner SW 1/4 sec. 24, T13N, R38E)

a small fault is exposed in a railroad cut on the north canyon wall of the Snake River. The fault is approximately 8 feet (2-1/2 m) wide. It consists of a shear zone filled with yellow-brown, poorly-indurated breccia, and a clay gouge seam that exhibits well-developed striae which rake 6°S. The clay gouge zone strikes N 20°W and dips 75°W, slightly divergent to a N 30°W air photo lineament, which appears to coincide with the fault. Offset of the flows exposed above the railroad tracks indicates that the west side is down-dropped about 10 to 15 feet (3 to 4-1/2 m). Exposure of the fault was not observed on the south canyon wall due to colluvium cover; however, it may pass through a small notch near the center of sec. 25 T13N, R38E. The maximum inferred length of the fault and the coinciding topographic linear is about 2 miles (3 km).

The near-horizontal (6°S) orientation of the striae exposed, the gentle westerly dip, and the west-side-down offset sugest a left-lateral slip on the Mile 72 Fault. This motion is consistent with that inferred for the Central Ferry Fault (located about 10 miles (16 km) to the eat) whose north end has a similar strike. colluvium overlying the fault zone above the railroad cut does not appear to have been cut. The colluvium appears to be of post-Spokane Flood age; thus, available exposures do not allow satisfactory dating of the youngest motion on the Mile 72 Fault.

3.2.1.5 Kooskooskie Faults. The Kooskooskie Faults are four generally north-south striking faults which extend from the Mill Creek area (T6N, R37 and 38E) northward into the study area (Plate 2). From west to east they are the Pikes Peak Fault, the Kooskooskie Fault, an un-named fault, and the Blacksnake Ridge Fault.

The Pikes Peak Fault (Kienle and others, 1979) extends from the west side of Pikes Peak (in T6N R37E, south of the project area) northward (N 5°W to N 10°W) to near Mill Creek sec. 22, T7N, R37E). The fault is not exposed, but is inferred on the basis of a prominent

topographic lineation which is nearly parallel to the Kooskooskie Fault, and on the presence of a groundwater barrier which is expressed as an alignment of seeps and hydrophilic vegetation. The age and total offset of the Pikes Peak Fault are unknown, but are inferred to be similar to the Kooskooskie and Blacksnake Ridge faults.

The Kooskooskie Fault (Newcomb, 1965) extends northward from the Mill Creek Monocline, south of the study area (Kienle and others, 1979), across Mill Creek (SE 1/4 sec. 18, T6N, R37E), east of Kooskooskie, and thence northward to near Mud Creek (NW 1/4 sec. 31, T8N, R38E). Swanson and others (1979) infer the fault to extend north of Mud Creek to near Coppei Creek (NW 1/4 sec. 6, T8N, R38E) based on the apparent juxtaposition of Grande Ronde and Frenchman Springs flows in Coppei Creek. The total length of Kooskooskie Fault could thus be in excess of 20 miles (32 km), including the portion south of the study area. At is south end, it is inferred to either connect with or be truncated by the north-northeast trending Blalock Mountain Fault, part of the Hite Fault System (Kienle and others, 1979). No exposures of the fault were found during this or previous work; however, attitudes of the basalt near the fault and apparent offsets give some indication of the fault motions.

Dips on both sides of the fault increase to 5° and 10°NW, away from the general 2° to 3°NW regional dip, suggesting gentle, west-facing drag folds. The tendency of the fault to deviate slightly to the east on highlands, suggests a slight westward dip. On the east end of Blacksnake Ridge (sec. 18, T7N, R38E), the fault offsets the Frenchman Springs Basalt about 300 feet (100 m) down to the west. Mapping by Swanson and others (1979) suggests between 100 and 200 feet (30 and 60 m) of offset at the north end of the fault.

On the north side of Mill Creek (NE 1/4 sec. 6, T6N, R38E), a vertical dike of Frenchman Springs Basalt 40 feet (12 m) in width is exposed coincident with the fault zone. Exposures are not adequate

to show if the dike intrudes the fault, or if the fault parallels or cuts the dike. Offset of Frenchman Springs Basalt by the Kooskooskie Fault to the north on Blacksnake Ridge suggests that, most likely, the fault follows or cuts the dike. However, dike emplacement and faulting could have been contemporaneous.

The easternmost of the Kooskooskie Faults was first mapped by Newcomb (1965). This fault, herein referred to as the Blacksnake Ridge Fault, extends from south of the study area, across Mill Creek near the west end of Indian Ridge, and thence northward across the west ends of Biscuit and Blacksnake Ridges (near the center of Tps 7 and 6N, R38E). An air photo linear south of Mill Creek suggests that the fault may continue south of the study area to a north sriking fault on the east side of Government Mountain (secs. 4, 9 and 16, T5N, R38E) and to the Hite Fault (Kienle and others, 1979). The Blacksnake Ridge Fault is apparently joined by the unnamed Kooskooskie Fault about 0.6 miles (1 km) north of Mill Creek, near the Oregon-Washington state line. Both of these faults have strong topographic expressions, similar to the Kooskooskie Fault proper, although the unnamed fault appears to be a narrower zoner with less offset.

On Blacksnake Ridge (sec. 21, T7N, R38E), the Blacksnake Ridge Fault cuts a distinctive glomerophyritic flow (possibly the Eckler Mountain Member of Swanson and others, 1979). The flow is offset about 520 feet (160 m) down to the west across the fault. About 2 miles (3 km) to the north, at Biscuit Ridge, the zone dips 85°W and striae rake 48°NW. The offset of flows, together with the striae, indicate dextral, oblique-slip motion, with a total throw of about 750 feet (230 m). The apparent sense of throw on the fault is compatible with the inferred dextral motion of the nearby Hite Fault System (Kienle and others, 1979). Together with their apparent proximity to, or connection with, the Hite System, the apparent offset suggests a possible genetic relationship of the Kooskooskie Faults and the Hite Fault System. The Kooskooskie Faults do not offset the upland loess or the alluvium in Mill Creek.

3.2.2 Wallula Fault System

The Wallula Fault System (Bingham and others, 1970) approximately parallels part of the postulated Olympic-Wallowa Lineament (Raisz, 1945). This system was previously defined (Kienle and others, 1979) as extending from about 2 miles (3 km) west of Wallula Gap (Figure 3) east-southeast at least 35 miles (55 km) to Milton-Freewater; based on the results of this earlier study, it was also inferred to extend an additional 15 miles (22 km) along the South Fork of the Walla Walla River to the Hite Fault. In addition to this main fault trend, several parallel and other related faults occur in and east of the Walla Walla Syncline, and are included in the Wallula Fault System (Plate 2). Previous work (Kienle and others, 1979) suggested that these faults occur as far north as Walla Walla, Washington, and Pikes Peak, Oregon (T6N, R37E). The present study, however, has shown that faults parallel or nearly parallel to the Wallula Fault System occur as far north as Lyons Ferry (T13N, R37E, described in Section 3.2.2.5) and as far east as Pomeroy (T12N, R42E, Ben Day Gulch Fault, Section 3.2.2.6). Motions on these faults are generally small, but they are oblique-slip or strike-slip faults similar to those of the Wallula System. Because of the similarities of strike and motion, such faults are discussed together with the Wallula Fault System. Further detailed structural mapping would be required to define the north boundary of the Wallula Fault System and the relationship, if any, of the many small, but similar, faults north of the main Wallula Fault Zone.

3.2.2.1 Wallula Fault

The Wallula Fault extends from near Umapine, Oregon (south of the study area in T6N, R35E) west-northwest to near Wallula Gap (Newcomb, 1965; Bingham and others, 1970; Swanson and others, 1977; Farooqui, 1979). Its extent within the area is shown on Figure 3 and Plate 2. About 3 miles east of Wallula Gap, the Wallula Fault appears to bifurcate. One branch continues on a N 70°W strike along the Horse Heaven Anticline's north flank, while the other, northern branch apparently swings into the Rattlesnake-Wallula Lineament

(Plate 2), as originally suggested by Laval (1956). Much confusion has arisen from various usages of the terms "Wallula Fault", "Wallula Gap Fault", "Rattlesnake-Wallula Gap Fault", "Rattlesnake-Wallula Lineament or Fault", "Horse Heaven-Wallula Fault", "Umapine Fault", etc. Thus, for this report, we propose that the terms Rattlesnake-Wallula Fault or Lineament be restricted to the north branch of the Wallula Fault; i.e., that part of the fault which lies north and west of the bifurcation near Wallula, and to the topographic linear which extends west-northwest of the fault to Rattlesnake Mountain. The term Wallula Gap Fault is restricted to the south branch of the fault, which actually runs through Wallula Gap, and that Wallula Fault is restricted to the fault east of the bifurcation. Together these faults are here referred to as the Wallula Fault Zone, because the available evidence suggests that they are all related to the same motions and stresses (Farooqui, 1979; Kienle and others, 1979; Bingham and others, 1970).

The Wallula Fault, regardless of its terminology, is the best- and most extensively-developed fault in the Wallula Fault System. ogether with associated tensional shears, such as those at Vancycle Canyon (T6N, R32E), it forms the south structural margin of the Pasco and Walla Walla basins. East of the study area, between Wallula Gap and the Oregon state line, the fault consists of a broad zone of gouge, and pulverized and sheared basalt between about 300 to 1,000 feet (100 to 300 m) in width. Further southeast, the fault continues to the Milton-Freewater, Oregon, area (Kienle and others, 1979). The abundant evidence of right-lateral, strike-slip motion in the zone east of Wallula Gap reported by Farooqui (1979) was largely confirmed during mapping for this study. Reported areas of young (post-glacial) faulting along the Wallula Fault Zone are east of the study area. These occurrences of faulted colluvium, Touchet beds and loess are discussed in some detail by Bingham and others (1970), Farooqui (1979) and Kienle and others (1979).

3.2.2.2 Wallula Gap Fault. As discussed above, the Wallula Gap Fault extends from east of the study area through Wallula

Gap (SW 1/4, T7N, R31E). It is inferred to cross the Columbia River and continue through the Yellepit Station area, and thence N 80°W along the north flank of the Horse Heaven Anticline, probably to at least the NE 1/4 sec. 12, T7N, R29E, near Johnson Butte, and possibly to a small fault exposed in Bofer Canyon (NE 1/4 sec. 5, T7N, R29E) in cuts on state Highway 12.

At Yellepit Station, the Wallula Gap Fault is a complex zone about 250 feet (80 m) in width. Detailed mapping of a trench across the zone, conducted by Hamill (in Farooqui, 1977), shows that the fault juxtaposes Frenchman Springs flows south of the fault with the Umatilla flow and Selah Member, north of the fault. Well-developed, subhorizontal to horizontal striae are present in margins of the main clayey silt gouge zone in a part of the trench which remains open. This zone strikes N 70°W and dips 85°N, similar to exposures of the fault east of the river.

Evidence for continuation of the Wallula Gap Fault northwest of Yellepit, as suggested by Bingham and others (1970), is less certain, but, in our opinion, convincing. First, the shear zone can be followed from the Yellepit area for 1 mile (1.6 km) along trend to the SE 1/4 sec. 19, T7N, R31E. This part of the fault is coincident with a strong, linear magnetic anomaly (Weston, 1977). The fault zone passes beneath loess and Touchet beds west-northwest of this point, but the strong magnetic linear continues west-northwest for an additional 17 miles (27 km) into T8N, R28E. At Nine Canyon, Farooqui (1977) reported tectonic breccia along the trend of the magnetic linear. He interpreted this breccia as axial plane shearing in the Jump Off Joe Anticline, a minor warp on the flank of the Horse Heaven Anticline. Examination of fresh roadcuts in Nine Canyon (center NW 1/4 sec. 16, T7N, R30E) show this breccia to be Umatilla flow-top breccial rather than tectonic breccia. However, the attitudes of the Umatilla flow and the overlying Selah Member and Pomona flow, strike N 80°W, dip

2°S, clearly show that this locality is part of the south dipping flank of the Horse Heaven Anticline, not the axis (as shown by Rockwell, 1979, and Swanson and others, 1977). In addition, the thickness of the Umatilla flow appears to be repeated across the magnetic linear; however, outcrops are not sufficient to define this relationship clearly. Together, the south dip and apparent excessive thickness of the Umatilla flow suggest a continuation of the Wallula Gap Fault to Nine Canyon.

Farther to the west-northwest, Farooqui (1977) inferred a thrust fault along the north side of Jump Off Joe. Mapping by Rockwell (1979) shows the Pomona flow top to be 400 feet (120 m) in elevation below the stratigraphically lower Umatilla flow top across the location of Farooqui's (1977) inferred fault, (sec. 6, T7N, R30E), and the magnetic linear. To account for the lower elevation of the Pomona the folding would require at least an 18°N dip on the north face of Jump Off Joe. Measured dips along strike to the east are, however, near-horizontal or southward, strongly suggesting a continuation of the Wallula Fault along the north face of Jump Off Joe.

West of Jump Off Joe (NE 1/4 sec. 10, T7N, R29E), dips along the north flank of the anticline steepen to 20°N, suggesting either dying out of the fault or significant drag folding. However, a fault mapped by Rockwell (1979) coincident with the magnetic linear 2 miles (3 km) fruther to the west-northwest suggests a continuation of the Wallula Gap Fault at least to state Highway 12, in Bofer Canyon (NE 1/4 sec. 5, T7N, R29E). Inferred offset of this fault is small (less than 20 feet [6 m] vertical) suggesting that the fault dies out.

The apparent motions across the inferred extent of the fault are consistent with the down-to-the north, right-lateral slip observed on the fault at, and east-southeast of, Wallula Gap. Together with the continuation of the matnetic linear, the apparent offsets strongly imply a continuation of the Wallula Gap Fault west-northwest of Yellepit Station to state Highway 12.

The youngest materials offset by the Wallula Gap Fault within the study area are flows of the Saddle Mountains Basalt. However, the fault merges with the Wallula Fault east of Wallula Gap, and that part of the Wallula Fault System appears to cut both Touchet beds and loess of post-Touchet age south of Umapine, Oregon (Kienle and others, 1979; Rockwell, 1979). Because of the connection, the Wallula Gap Fault also has the potential for young offset.

3.2.2.3 Rattlesnake-Wallula Lineament. The Rattlesnake-Wallula Lineament (Jones and Deacon, 1966) extends from the north end of Rattlesnake Mountain (northeast of study area in T11N, R26E) to Wallula Gap (Plate 2). East of Wallula Gap, the lineament apparently merges with the Wallula Gap Fault, as discussed in Section 3.2.2.2. In the study area, the lineament is expressed as a series of five approximately aligned hills between Wallula Gap and Vista (NW corner T8N, R29E), and as a fault of unknown length northwest of Wallula Gap. In detail, the hills constituting the lineament are canoe-shaped, doubly-plunging anticlines (brachyanticlines), whose axes diverge slightly southwards from the west-northwest strike of the Rattlesnake-Wallula Lineament.

Because the Rattlesnake-Wallula Lineament lies along the Cle Elum-Wallula Lineament (CLEW) or central portion of the controversial Olympic-Wallowa Lineament (Raisz, 1945) much speculation has centered on it. In 1970, Bingham and others wrote, "Much has been written about this Rattlesnake Hills-Wallula topographic lineament, but to date there is no widespread agreement as to the origin of the lineament or the breccias associated with it." Unfortunately, if Bingham and others (1970) were writing today, this statement would still be true.

Several breccia zones which occur along the Rattlesnake-Wallula Lineament, and the geometry of the associated folds provide evidence for dextral slips on the lineament, consistent with the motion on the connected Wallula and Wallula Gap Faults. The most definitive exposure is that at Finley Quarry, on the east end of The Butte

(SW 1/4 NE 1/4 sec. 3, T7N, R30E). The fault exposed at Finley Quarry juxtaposes the Umatilla flow (south side) with pre-Spokane Flood colluvium. Several shear and gouge zones constitute the main fault (Figure 4). The largest and southernmost consists of 2 to 4 feet (0.6 to 1 m) of angular to subrounded clasts of Umatilla Basalt in a tan silt matrix. This zone strikes N 70°W and dips about 85°N. Near the top, the zone rolls over to a south dip. The curved shape of the zone, together with the well-developed horizontal striae at both contacts of the zone, constrain motion on it to horizontal. Lesser shears north of the main shear (Figure 4) include tectonic slices of the Selah Member and Pomona flow. One of the larger of these lesser shears occurs within and at the margins of a tectonic slice of the Selah Member (Figure 4). This slice has been sretched, and locally kinkbands have been introduced into the laminated tuffs of the slice. The slice has a N 45°W strike, and 70°NE dip. Margins of the slice have striae which rake 85°W. Between the northern shears and the tectonic slices of Selah, is a rubbly tectonic breccia which consists of Pomona clasts in a clayey silt matrix (Figure 4).

The northernmost shears exposed at Finley Quarry reveal faulted colluvium (Figure 4), which has been examined by several investigators since enlargement of the cutface a few years ago (e.g. Rockwell, 1979; Farooqui, 1977; Farooqui and Thoms, 1980). In detail (Figure 4), the northern fault consists of two strands, 4-1/2 to 5 feet (1 to 1-1/2 m) apart, separated by a small graben-like block of colluvium. On the south, this block is juxtaposed with the coarse breccia containing Pomona [illegible]ts, while on the north it is juxtaposed with a colluvium of slightly different origin. A third colluvial layer passes undisturbed across the entire fault zone.

The differences among these three types of colluvium are critical to understanding the offset of the fault and its age. The first type, which occurs in the small graben-like block and overlies the coarse breccia, is predominantly composed of fault breccia; however, the

breccia materials are mixed with crudely stratified colluvium (Figure 4) and loess. Thus, this colluvium likely represents a mix of material shed from the adjacent breccia and local colluvial and loessal debris. The clast assemblage is entirely volcanic, and dominantly basaltic.

The second type of colluvium also has a dominantly basaltic clast assemblage; however, it has only a minor amount of tectonic debris, and is heavily impregnated with caliche. This colluvium occurs only north of the fault zone. Both these colluvial types lack clasts which characterize glaciofluvatile deposits of the Spokane Flood.

The younger, overlying, unfaulted colluvium is also dominantly basaltic and loessal, and has a few tectonically-faceted clasts. However, it also contains scattered rounded pebbles and cobbles of the quartzite, chert, and plutonic and metavlocanic rocks which characterize the glaciofluvatile gravels. This younger colluvium is post-Pleistocene in age.

3.2.2.4 Burr Canyon Fault. The Burr Canyon Fault is exposed in railroad cuts (SE 1/4 sec. 24, T12N, R33E) along the north bank of the Snake River near Burr Canyon. The fault is inferred to extend northwest, parallel to Burr Canyon, for about 2 miles (3 km), and southeast across the Snake River. It probably continues 10 miles (16 km) further southwest along a prominent tonal linear defined by Sandness and others (1979), to a small fault near Clyde (SW 1/4 T11N, R35E).

Exposures of the fault in the Burlington Northern railway cut (1/3 mile south-southwest of Burr Canyon) reveal two main shears, both striking N 55°W and dipping 85°SW. The west shear consists of 1 to 2-1/2 feet (.3 to .8 m) of gray, cemented, basaltic breccia, while the east shear consists of 2-1/2 to 4 feet (.8 to 1.2 m) of

uncemented, orange-brown-stained brecciated basalt in a clayey silt matrix. Striae on the margins of both zones rake between horizontal and 25°S. The Vantage horizon, which is well exposed on both sides of the fault, is offset about 35 feet (11 m) down to the east, while the top of the lowest flow of the Frenchman Springs Member is offset about 30 feet (9 m), also down to the east. About 25 feet (8 m) of the total apparent vertical offset occurs across the western shear. Flows northeast of the fault dip about 1°NE, and flatten to near-horizontal near Burr Canyon; flows southwest of the fault appear horizontal. Thus, dip of the flows and rake of the striae indicate that right-lateral slip produced the observed down-to-the-east offset.

The west shear is overlain by colluvium and loess. The east shear is overlain by unfaulted glaciofluviatile gravels, which in turn are overlain by loess. Southeast of the Snake River, loess covers the fault trace.

3.2.2.5 Lyons Ferry Fault. The Lyons Ferry Fault extends from 1 mile (1.6 km) north of Lyons Ferry (NE 1/4 sec. 19, T13N, R37E) southeast to the Snake River's south bank (NW 1/4 sec. 6, T12N, R38E), a distance of about 6 miles (10 km). In cliffs east of the Palouse River (NW 1/4 sec. 20, T13N, R37E), the fault offsets the Vantage horizon about 60 feet (18 m), down to the north. Southeast of the Palouse River, the fault follows a prominent topographic and photographic lineation noted by Slemmons (1979). The fault is exposed on the south bank of the Snake River (NW 1/4 NW 1/4 sec. 6, T12N, R38E). The fault zone is about 18 feet (5.5 m) in width and contains three distinct gouge zones. The gouge zones vary from a few inches to over 3 feet (1 m) in width, and consist of orange-brown basaltic rubble in a clay silt matrix. Two of those shears display striae which rake 50°N. Total vertical offset is about 8 feet (2.4 m), down to the southwest. The difference in apparent sense of vertical offset and oblique striae indicate a large component of strike-slip

motion on the fault. The zone forms a distinct notch in the cliff, which is filled with unfaulted, post-Spokane Flood colluvium.

3.2.2.6 Ben Day Gulch Fault. The Ben Day Gulch Fault is a west-northwest striking fault which is named for its excellent exposures in Ben Day Gulch, approximately 2 miles (3.2 km) northeast of Pomeroy (NE 1/4 NW 1/4 sec. 28, T12N, R42E). The fault is exposed in cuts on the east side of the Gould City-Mayview Road, at about elevation 2,230 to 2,250 feet (680 to 686 m) (MSL), and extends east-southeast along a linear stream. A similar, but smaller, fault exposed north of Pataha on Bell Plain road, (NW 1/4 SW 1/4 sec. 35, T12N, R42E) is apparently a continuation of the Ben Day Gulch Fault into the northwest flank of the Pataha synform (refer to Section 3.2.1.1).

In the exposures on the Gould City-Mayview Road, the fault consists of a zone of pulverized and/or shattered reversed and normal polarity Wanapum Basalt (phyric Frenchman Springs and Roza) which is about 90 feet (28 m) in width. Two major and several lesser shears are present within the zone. They strike N 35°W to N 45°W and dip 75° to 85°NE. The largest and northernmost shear (Figure 5) consists of 15 to 17 feet (4-1/2 to 5 m) of well-indurated, red-brown to orange-brown, basaltic breccia in a clay silt matrix. The north margin of this shear is a hard red silty clay gouge, 6 inches to 1 foot (15 to 30 cm) wide, with well-developed horizontal striae. A seam of white caliche fills a 3/4- to 1-1/4-inch (2- to 3-cm) wide fissure between the red silty clay gouge and the adjacent shattered Roza Basalt (Figure 5). The other major shear lies about 40 feet (12 m) south of the large north zone. It consists of 3-1/2 to 4 feet 91 to 1.2 m) of indurated breccia similar to that in the north shear.

The area between the two main shears just described is a complex zone of breccia, shattered basalt and tectonic breccia, all cut by

many small secondary shears. The most prominent of these shears strikes N 80°E, dips 50°S, and has a reverse slip (Figure 5). It juxtaposes basalt flow breccia (on its south side) with caliche-rich colluvium derived from the fault zone (on its north side). Caliche lines the shear, and appears to have been locally broken and rehealed along it. The colluvium and breccia are both overlain by unfaulted loess.

The southeast exposure of the fault on Bell Plain Road (NW 1/4 SW 1/4 sec. 36, T12N, R42E, elevation 2,300 feet) reveals a small zone 6 to 8 inches (15 to 20 cm) in width of orange-brown basalt breccia in a clay silt matrix. The zone strikes N 50°W and dips 83°NE. Striae at the margins rake 10°SE. Vertical offset is small, likely less than 2 or 3 feet (0.6 to 1m). The zone is overlain by unfaulted gray-brown loess (post-Touchet?). Offset of the fault is apparently strike-slip, based on the striae and the small vertical component of throw at both exposures. The sense of offset, however, is not apparent. The fault strikes similarly to the right-slip Wallula Fault System; however, it is located on trend to the Hite Fault and may be related to it rather than to the Wallula faults.

3.2.2.7 College Place Flexure. The College Place flexure (Newcomb, 1965) is a groundwater barrier which trends north-northeast for about 10 miles (16 km) along the north flank of the Walla Walla Syncline between Whitman (SE 1/4 sec. 36, T7N, R34E) and Walla Walla (NE 1/4 sec. 20, T7N, R36E). North of the flexure (Plate 2), the sub-surface elevation of the Columbia River Basalt is about 200 feet (60 m) higher than it is to the south. When wells were first drilled into the basalt in the College Place area (T7N, R35E), the wells south of the flexure had artesian flows, while those to the north had pressure levels some 200 feet (60 m) lower (Newcomb, 1965).

Although location of the flexure is well-defined by water wells, it is not clear whether the groundwater barrier and the relief in

the basalt are caused by faulting or by a monoclinal fold, although Newcomb (1965) shows the flexure as a buried fault. No surface expression of the flexure was found during this investigation.

3.2.2.8 Prospect Point Fault. The Prospect Point Fault is inferred to trend east-west along Mill Creek North of Prospect Point Ridge (SE 1/4 corner sec. 15, T7N, R37E to SE 1/4 sec. 17, T7N, R36E). The location of the fault (Plate 2) is closely fixed by water well data (Newcomb, 1965), which show a measurable change in the elevation of the groundwater surface across the fault. The elevation of the top of the basalt also changes across the inferred fault, with the south side about 50 to 100 feet (15 to 30 m) higher than the north side (Figure 6). Some of this difference may, however, be erosional. No outcrops of the zone were found, so its age remains unknown.

3.2.2.9 Promontory Point and Buroker Faults. The Promontory Point Fault (Plate 2) extends east-southeast from the Walla Walla Basin along the south side of Prospect Point Ridge onto the flank of the Blue Mountains (Tps. 6 and 7N, Rs. 36 and 37E). The west end of the fault was located by Newcomb (1965) on the basis of a difference between groundwater temperatures in the basalt north and south of the structure. Wells immediately south of the fault have anomalously warm water, while those to the north have normal-temperature or anomalously cool water. The fault extends from beneath the alluvial fill of Russel Creek onto the Blue Mountain flank along a prominent linear ditch that trends straight up the regional dip slope into the Pikes Peak area (south of study area). The linear is well-expressed on U-2 photos and in the topography, particularly in the N 1/2 sec. 10, T6N, R37E.

The fault itself is not exposed; however, the apparent offset can be observed in several places. Southwest of Kooskooskie (SW 1/4 sec. 11, T6N, R37E) along McKay Grade Road the fault juxtaposes a

phyric flow of the Frenchman Springs Member (southside) with a Grande Ronde flow (north side). South of Prospect Point, Dodge flows (Eckler Mountain Member), which are exposed at or above 1,309 feet (400 m) (MSL) along Russell Creek Road, are downdropped at least 250 feet (76 m) south of the fault (Figure 6).

The apparent downward offset on the south side is probably not a consequence of simple, normal faulting. This is suggested by five small related faults exposed in cuts on Russell Creek Road (sec. 31, T7N, R37E) about 5 miles south of Buroker. These faults are informally known as the "Buroker faults", after the name given one of them by Farooqui (1980). The westernmost of the Buroker faults (center NW 1/4 sec. 31) cuts two Dodge flows in a small borrow area on the north side of Russell Creek Road. This fault was first mapped by Swanson and others (1979a). Earlier mapping by Newcomb (1965) noted the anomalous dips of the Dodge flow, but the shear zone was not exposed until recently. The fault strikes N 30°E and dips 49°NW. It consists of a 2- to 3-inch (5- to 8-cm) zone of gray clayey silt gouge, which has well-developed striae at both contacts, with the adjacent basalt. The striae rake 45°N. The top of the Dodge, a few yards east of the fault, strikes N 55°E and dips 40°NW. The low angle between the fault and the flow top makes estimation of the offset difficult, but, if the flow top exposed west of the fault is the same as that to the east, then the apparent offset is normal, with the northwest side down. If this assumption is correct, the striae then suggest a right-lateral oblique slip.

About 1,850 feet (565 m) east of the westernmost "Buroker fault" another fault zone is exposed in cuts on Russell Creek Road (NW 1/4 SW 1/4 NE 1/4 sec. 31, 200 feet (60 m) east of 1/4 section fence). Two shear planes are present in the zone: one which juxtaposes cemented tectonic basalt breccia with colluvial gravels and loess; and another, opposite to the first fault, which cuts only the breccia. The first of these faults appears to be the larger of the two. It strikes

approximately N 15°E and dips 31°WNW (Figure 7). The striae on the contact between this shear and the footwall rake 30°NW. Basalt breccia, on the west side, is juxtaposed with post-basalt sediments (old loess overlying gravels) on the east side. Thus, the apparent offset (Figure 7) is that of a thrust, up to the west, with a large component of left-lateral slip. The second, lesser shear also strikes about N 15°E; however, it dips about 30°ESE, and its east side is offset upward a few inches, forming a small, horst-like wedge at the end of the upper plate of the thrust (Figure 7). The apparent throw of the top of the basalt on the main shear is about 3 feet (1 m) in the plane of the outcrop. Taking the orientation of the striae (30°NW) into account yields an estimated total throw of about 6 feet (2 m).

Examination of this fault shows it to be the fault discussed by Rockwell (1979, p. II-115); they interpreted it as cutting "overlying gravels and an older loess", but state that it "does not deform overlying, younger loess." A subsequent examination of the fault by Farooqui and Thoms (1980) is less clear. Farooqui and Thoms (1980, Figure 10) show a fault between the western-most "Buroker fault" and the thrust (SW 1/4 NE 1/4 sec. 31); however, their photographs (Farooqui and Thoms, 1980, Figure 12), are clearly of the fault described above (in NW 1/4 SW 1/4 sec. 31).

East of the thrust fault, three other shear zones are exposed in cuts on Russell Creek Road. Two are exposed in a borrow pit about 200 feet (60 m) west of the Junction of Russell Creek and Foster Roads (NE 1/4 SE 1/4 NE 1/4 sec. 31). Both are exposed in the north wall of the borrow pit as vertical zones of poorly-indurated orange-yellow basalt breccia in a clayey silt matrix. The zones vary from a few inches to about 1 foot (.3 m) in width, and appear to have caused little or no vertical offset of the exposed Frenchman Springs flow. The western fault strikes N 45°W, while the eastern fault strikes due north. The easternmost "Buroker fault" is similar to

these two faults, and is exposed about 100 feet (30 m) to the east of them in a roadcut along Russell Creek Road, near the Foster Road. The fault strikes north, is vertical and consists 3 to 6 inches (7 to 15 cm) of poorly-indurated basalt breccia in a yellow-orange clayey silt matrix. Large horizontal striae observed on the westernmost of these three faults, together with the lack of vertical offset, suggest strike-slip offset.

The "Buroker faults", are all near the location of the Promontory Point Fault (Kienle and others, 1979) inferred by Newcomb (1965) based on the well data. The orientations and inferred or observed motions on the "Buroker faults" are consistent with an origin as secondary shears associated with dextral strike-slip on the Promontory Point Fault. Indeed, if the south-down offset of the Promontory Point Fault was consequence of normal faulting, it would be expected that the "Buroker faults" would also be normal faults parallel to the main faults.

Four of the five "Buroker faults" cut basalt and are overlain only by "young" loess; i.e. light tan eolian silt and fine sandy silt, which is similar to the post-Touchet loess mapped as "loess undifferentiated" by Newcomb (1965). This loess is very similar in petrology to the Touchet beds, and appears to have been in large part derived from them. The remaining "Buroker Fault", the thrust fault in NW 1/4 SW 1/4 NE 1/4 sec. 31, cuts basalt, gravels, loess and is overlain by unfaulted loess (Figure 7); it thus provides somewhat more information on the chronology of movement than the other faults.

The youngest material cut by the thrust fault in the "Buroker faults" is the tan loess, derived from reworking of the Touchet beds. As shown in Figure 7, only the lowest part of this loess is faulted. Both the underlying brown loess (Palouse) and the gravels are cut in their entirety (Figure 7). The gravels consist of subangular

to subrounded pebbles, cobbles and boulders of basalt in a sandy silt matrix (Figure 7). They are well-indurated but not cemented. Because of their composition, their position beneath the Palouse, and their proximity to nearby outcrops mapped by Newcomb (1965) as "old" or Pleistocene gravels, these gravels are also thought to be part of the "old" or Pleistocene gravels of the Walla Walla Basin.

The offset of the materials cut by the fault is difficult to measure because of the lack of exposure of unfaulted Dodge flow west of the fault, and the syntectonic sloughing of the gravels from the fault scarp. However, the offset of the Dodge flow is clearly greater than that of the gravels, which is in turn, greater than that of the loess. Thus, it appears that the offset occurred progressively over a long time period, rather than in one episode. The youngest motion must have been during Holocene time, since it cut materials reworked from the Touchet beds.

No direct evidence is available for the age of the related Promontory Point Fault. However, if one accepts the apparent genetic relationship, then the motion on it must also be young. This conclusion is consistent with ages of other faults in the Wallula System west and south of the area (Kienle and others, 1979) which cut Touchet beds and post Touchet loess.

3.2.3 Service Anticline and Sillusi Buttes

The Service Anticline is a 26-mile (42-km) long, north-south trending series of anticlinal segments. The structure emerges from the regional north dip of the Blue Mountains Anticline north of the Butter Creek drainage (sec. 4, T1N, R28E) at Service Butte, and is inferred to continue along a series of small, isolated basalt knobs northward to Umatilla Butte and Sillusi Butte. Previous mapping of the structure was performed by Kienle and Newcomb (1973), and the Sillusi Butte area was mapped by Anderson (Swanson and others, 1979). About 2 miles (3 km) north of the Columbia River, the axis of the structure bends sharply toward the northeast parallel to the Columbia

Hills Anticline (Figure 3). This sharp divergence from the north-south alignment of the structure defines the northern terminus of the Service Anticline.

The Butter Creek drainage lies on the northern flank of the east-west trending Reith Anticline and associated folds in an area where regional dips range from 2° to 7°N. In secs. 22 through 27, T1N, R28E, low-amplitude, parallel folds were mapped east of the projected axis of the Service Anticline. South of Butter Creek, about 1 mile (1.6 km) west of Vey Ranch, a major change in upland maximum elevation was observed with the eastern portion appearing down-dropped relative to the west. This change is inferred to occur across a fault; no gouge or breccia zones were located on either canyon wall, although the alignment may cut through a colluvium-filled channel north of Butter Creek. This possible fault may be a continuation of the fault mapped east of Service Butte. In Butter Creek Canyon, no dip reversals were observed which would indicate a continuation of the Service Anticline.

The Service Anticline appears to emerge from the regional north dips to form Service Butte which displays over 500 feet (152 m) of vertical structural relief and is approximately 2 miles (3.2 km) wide. A north-northeast trending fault emerges, in the E 1/2 sec. 4, T1N, R28E, as evidenced by a 90° change in strike on the lower eastern flank of the Service Anticline, and by offset of the Frenchman Springs flows. No gouge or breccia zones for this fault were observed due to loess and colluvium cover; however, the trace of the fault is inferred to follow an unnamed linear drainage along the county road between sec. 4, T1N, R28E and sec. 27, T2N, R28E.

The anticlinal axis at Service Butte exhibits mild westerly dips (around 2 to 5 degrees) and steeper easterly dips (5 to 15 degrees). The northern end of the structure plunges under loess-covered colluvium and glaciofluvial deposits. East of the butte,

the dips flatten into the regional pattern across a minor monocline. Within Service Canyon, the Frenchman Springs-Grande Ronde Basalt contact (Vantage horizon) expresses the anticlinal structure of the butte clearly. This canyon may be a fault-controlled diagonal cut across the anticlinal axis; however, no evidence of this was observed during field mapping.

From Service Butte north to Hermiston Butte (sec. 10, T4N, R23E) the Service Anticline is exposed only as a few isolated low-relief basalt knobs in a north-south line. The structure is concealed beneath glaciofluvial deposits and loess. Following the anticlinal axis northward, the next significant exposure is Hermiston Butte, which appears slightly offset to the east from the inferred main axis. At Hermiston Butte, east-dipping attitudes of the exposed Pomona and Umatilla flows indicate that Hermiston Butte is a portion of the eastern limb of the anticline. The dips range from 10° to 25°E.

Two northwest-striking faults are inferred to trend diagonally through the anticline at Hermiston Butte. They are covered with glaciofluvial deposits, and no gouge zones were observed. These faults strike about N 50°W, and bound the north and south ends of the major exposure at Hermiston Butte. The northern fault was inferred previously by Kienle and Newcomb (1973) based on relative positions of the top of the Pomona flow. The southern bounding fault, mapped during field work for this study, is based on similar evidence. The butte appears to be uplifted between these two faults. A third fault, trending north-south, is inferred along the anticlinal axis west of the butte based on the absence of the west flank of the anticline. No gouge zones were observed to substantiate this fault.

A new roadcut on the west side of Hermiston butte exposes indurated gravels (Ringold?) overlying the Selah Member, which, in turn, overlies the Umatilla flows. The gravel-Selah contact dips 25°NE, indicating that deformation of the structure was occuring during deposition of these pre-mid-Pleistocene gravels.

Further north, in secs. 22, 27, 28, 33 and 34, T5N, R23E, is the Umatilla Butte exposure of the Service Anticline. At this exposure the Service Anticline has an amplitude of over 150 feet (46 m) and an exposed width of 1/2 mile (0.8 km) at its widest portion. Dips on both exposed limbs show the east flank dipping more steeply than the west. Dips range from 6° TO 20°E, and from 3° to 7°W in the main exposure and 15°W at the northern extremity.

The eroded notch at the Umatilla city landfill exposes the axis of the anticline in Umatilla Butte (NE 1/4 SE 1/4 sec. 28, T5N, R28E). There, Pomona Basalt is exposed overlying the Selah beds and the Umatilla Basalt. At the southern margin of the landfill, a fresh cut through surficial materials exposes a portion of the fault inferred to parallel the anticline. The exposure of this zone, in a shallow bulldozer trench, is primarily a horizontal surface exposure. The exposed fault zone contains at least 25 feet (8 m) of brecciated and partially-opalized gouge, which includes several north-south trending vertical shears with striae raking from horizontal to slightly southwards.

Two diagonal faults, located in the NE 1/4 and SE 1/4, sec. 28, T5N, R28E, were inferred by Kienle and Newcomb (1973) at the north end of Umatilla Butte. Existence of one of the inferred diagonal faults in the NE 1/4 sec. 28 was confirmed by fresh rock cuts at the north end of the Umatilla landfill. The exposed fault consists of an 18- to 20-inch (.5- to .6-m) wide gouge zone composed of gray silt and angular basalt fragments. This fault strikes N 40°W, dips 88°S, and has horizontal striae. This fault aligns with a notch through the butte along Bensel Road, and appears to offset the anticlinal axis to the west, north of Bensel road. Another small strike-slip fault about 1 mile (1.6 km) north (NE 1/4 sec. 21, T5N, R28E) was exposed in a rock quarry. This fault contained 12 to 18 inches (.4 to .5 m) of yellow-gray silty gouge and horizontal striae. This zone also trends N 40°W and dips 70°N. Offset on these faults

appears to be small. Overlying loess and glaciofluvial deposits appeared uncut by the faulting; however, exposures of post-basalt sediments were limited to a thin mantle or were completely stripped away.

The Sillusi Butte exposure of the Service Anticline in secs. 28 and 33, T6N, R28E and sec. 4, T5N, R28E, displays about 500 feet (152 m) of vertical relief and has a width of slightly less than one mile (1.6 km) (Plate 1, Figure 8). Near the Columbia River, the east limb of the fold decreases laterally from a dip of 15° to 24°E near the axis. The west limb dips 7° to 12°W, although one outcrop appears to dip nearly 20°W (Kienle and Newcomb, 1973). Kienle and Newcomb (1973) mapped a north-south trending 2.5- to 3.0-mile-long (4- to 5-km) reverse fault on the anticline's west limb based on outcrop positions. However, the length of the fault appears to be less than 2 miles (3 km) based on the unfaulted steeply-dipping limbs found at the northern exposure of the trend. A fault trending about N 30°W was mapped at Sillusi Butte's southwestern exposure (SW 1/4 sec 4, T5N, R28E). Pomona Basalt on top of the butte overlies Umatilla Basalt that is juxtaposed against Pomona near the river edge to the west. No gouge zones were located; however, topographic notches disclose the fault's alignment. A small 1-foot (0.3-m) thick gouge zone trending n 7°E in a roadcut was observed in the SW 1/4 SE 1/4 sec. 4, T6N, R23E. The sense of motion, based on striae raking 22°N indicates oblique slip with 60° dip. Vertical offset appeared to be 3-1/2 feet (1 m), with the east side down-dropped.

At a new borrow source located 2 miles (3 km) north of the river (SE 1/4 SW 1/4 sec. 28, T6N, R28E) where anticline axis is exposed, both limbs of the anticline exposed near the axis dip 35° away from the axis and slightly south. Just beneath these steeply dipping limbs is an axially-located breccia. Due to the acute angle of the anticlinal fold, it is thought that the breccia zone was caused by crushing of the basalt along the anticlinal axis. No significant offset across it was found in exposures at elevations

of 900 feet (275 m) and 700 feet (213 m). A small, diagonal, strike-slip fault was located trending N 60°W in the east wall of the borrow source at the southern end of this butte. Kienle and Newcomb (1973) mapped an inferred fault with the south-side down in this location. The fault strikes N 60°W, dips 78°N, and contains 1.5 feet (0.5 m) of orange-brown breccia with striae raking 5°E. Post-basalt sediments appear uncut by the fault on the east wall. The west wall of the borrow source contains glaciofluvial deposits and erratic boulders with a thin loess cover. Underlying basalt is poorly exposed. Several large basalt boulders in the glaciofluvial deposit were cracked or split vertically; these crevices were filled with fine-grained clastic dikes (see Figure 9) up to 4 inches (10 cm) wide. These boulders are on the projected alignment of the fault described above, and could indicate post-Spokane Flood motion.

The Service Anticline axis turns sharply northeastward in the S 1/2 sec. 28, T6N, R23E, where it merges with the Columbia Hills Anticline. A doubly-plunging exposure of this structure exists in the N 1/2 sec. 27, T6N, R28E. it is apparently symmetrical, with flanks dipping 17° exposed as dip slopes on the southwest side. A fault inferred by Kienle and Newcomb (19730 appears to offset the anticline axis northward slightly east of this point.

East of the Service Anticline toward Lake Wallula, low-amplitude folds were mapped on the basis of small dip reversals and apparent dip slopes. Previous mapping (Swanson and others, 1979) has delineated folding in the area; however, mapping for this report has expanded upon and modified their findings. An east-northeast trending fault, was mapped about 2 miles (3 km) east of McNary Dam, based on Pomona Basalt exposures along the north canyon wall, and appears to die out into a monocline under glaciofluvial deposits. The Pomona Basalt appears to be down-dropped with an apparent offset of

about 100 feet (930 m) on the southern side of an eroded channel that trends about N 70°E. No gouge zone was observed, so the motion is not known; however, a reverse or thrust offset is suspected. This fault appears to splay off the Service Anticline, and could be related to a thrust fault mapped in the powerhouse foundation at McNary Dam, as shown in Plate 1 and Figure 8.

About 3 miles (5 km) upstream from McNary Dam (NE 1/4 sec. 6, T5N, R29E) an apparent offset in a stream channel trending N 60°E indicates a similar fault with about 50 feet (15 m) of offset. The northern block is downdropped. The fault appears to die out into a small syncline upslope from the river. No faults or folds mapped in the north side of Lake Wallula could be traced to the southern side, largely because of the extensive cover of glaciofluvatile gravels.

The field mapping indicates that the Service Anticline is a series of several doubly-plunging anticlinal segments, whose axes roughly parallel the overall north-south trend of the structure. Several lines of evidence, however, point to the presence of a fault along or parallel to the axes of the series of anticlinal segments. These include: 1) offset of the Blue Mountains slope across Service Butte, and offset of the Frenchman Springs flows east of Service Butte (Plate 1); 2) the vertical, north-south, strike-slip shear zone in Umatilla Butte; 3) the large, axially-located crush zone north of Sillusi Butte; and 4) the several short, northwest-striking, strike-slip or oblique-slip faults which segment the anticline. The apparent geometry is consistent with left-lateral conjugate Reidel-shear faulting (Wilcox and others, 1973). This mechanism of formation requires maximum stress in roughly a north-south-oriented couple with a strong east-west compressional stress component.

The axially-located partial exposure of a large, north-south oriented, strike-slip fault zone at the Umatilla city landfill is thought to be the major slip axis for the north-south-oriented stress

couple. This stress field with a strong east-west compressional stress component would probably form the anticlinal segments directly over the major fault, particularly in the unconfined surface-basalt flows and relatively weak interbeds, such as the Selah and Mabton Members.

At Hermiston Butte the absence of the anticline axis and west limb can be attributed to erosion of these portions during catastrophic floods, as a direct result of the weak rock conditions along the axial fault, or to the west limb having a relative down-dropped displacement along the fault, with burial by glaciofluvial deposits, or to a combination of these processes. At Sillusi Butte, the anticline is crosscut and offset laterally by at least three diagonal conjugate shears, and is bounded on the west by three inferred faults. The fold dips steeply and was found to contain an axially-located, breccia zone, with little or not offset, between the limbs dipping 35°. It is probable that the left-lateral shearing motion apparent at Umatilla Butte has translated into the minor folds and possible thrusts northeast of McNary Dam.

The terminus of the north-south structure was apparently controlled by the northeast-trending Columbia Hills Anticline. The northward compression on the east side of the Service Anticline appears to be "backed up" by the obstruction (Columbia Hills Anticline), and has caused small-amplitude northeast-trending folds and associated thrust faults that were mapped east of the anticline axis. These folds and related faults appear to splay off the north-south structure into a N 30-35°E trend, roughly paralleling the Columbia Hills Anticline. Minor strike-slip or thrust faulting could be expected near the major strike-slip fault juncture; at a greater distance along the splays, folding would be the manifestation of compressional, non-shearing stress. A fault inferred from the Pomona Basalt exposure east of McNary Dam appears to fit this model. Faults mapped within the foundation excavations for McNary Dam could not be directly correlated with any

structures mapped on the surface; however, it is thought that the faulting is probably associated with the northeast-trending structures mapped northeast of the dam.

Previous studies by Kienle and Newcomb (1973) have assigned a minimum age of deformation related for the Columbia Hills Anticline of 0.9 million years, based on K-Ar age dates of the undeformed Haystack Butte Flow of the Simcoe Lavas. The Service Anticline is considered to have been formed during the same Plio-Pleistocene deformation that formed the Columbia Hills Anticline and related structures, due to the merged nature of the intersection; neither fold belt has deformed an older belt. With the notable exception of the broken glaciofluvial boulders in a borrow source on Sillusi Butte (SE 1/4 SW 1/4 sec. 28, T6N, R23E), no evidence was observed which would require modification of this conclusion. The broken boulders are thought to lie over a conjugate Reidel shear fault, and may indicate post-Spokane Flood age motion on the fault. This possibility could not be confirmed during our field studies.

3.3 Tectonic Interpretation

Previous interpretations of the structural geology of the areas investigated have envisioned the Blue Mountains Anticline and Pasco and Walla Walla basins as broad, approximately symmetrical folds with only moderate or infrequent faulting (e.g. Walker, 1973, 1979; Newcomb 1970; Swanson and others, 1979a). Similarly, the Service Anticline has previously been interpreted as a linear anticline with local culminations and sags and only minor faulting (e.g. Newcomb, 1970; Kienle and Newcomb, 1973). Previous studies have not discriminated among different ages and episodes of structural development, although some structures, in particular those related to the Rattlesnake-Wallula Lineament and the Wallula Fault, have been identified as younger than other structures in the area (e.g., Bingham and others, 1970; Farooqui, 1979; Kienle and others, 1979).

The new data presented herein document two distinct sets of faults within the areas studied: north to northeast striking faults which have

motions and ages which appear compatible with deformation of the Hite Fault; and northwest to west-northwest striking faults which have motions apparently consistent with deformation of the Wallula Fault System.

The new data also demonstrate extensive strike-slip movements on several faults. Indeed, our observations suggest that strike-slip and oblique-slip motions have been the dominant mode of deformation within the Pasco and Walla Walla structural basins, with significant dip-slip motions confined to the margins of these basins.

Several studies of focal mechanisms and tectonics have postulated a generally north-south maximum compressive stress for southeastern Washington and northeastern Oregon (Smith, 1977, 1978; Kienle & Newcomb, 1973); Bingham and others, 1970; WPPSS, 1977) from the Late Cenozoic to the present time. In such a regime, normal faults would be expected to trend generally north, while dextral (right-lateral) and sinistral (left-lateral) faults should strike northwest and northeast, respectively. Thrust faults should strike east. Fault trends between these orientations should exhibit appropriate combinations of these motions. Perplexingly, however, the strike-slip motions observed, or inferred, are dextral for both the north to northeast striking Hite Fault System and for the north west to west-northwest striking Wallula Fault System, while the newly-documented north-striking fault along the Service Anticline appears to have a sinistral offset. Dextral motion observed on several of the west-northwest striking Wallula Fault System faults is compatible with a north-south maximum compressive stress. However, dextral motion on the Hite Fault System, and sinistral motion on the faulted Service Anticline are not compatible with any simple model involving north-south compression.

Two simple hypotheses could explain the anomalous dextral motion on the Hite Fault System, and sinistral motion on the Service Anticline. First, the Hite System may be of a different age than the Service Anticline or Wallula Fault System, and, consequently, it may have formed

in response to a stress field of quite different orientation. Second, it is possible that the faults are all approximately the same age, and are a result of a non-uniform compressive stress.

We favor the first hypothesis for three primary reasons. First, there is some evidence that the Wallula Fault System and Service Anticline have moved more recently than the Hite Fault System. Many faults in the Wallula Fault System appear geomorphically young, with only moderate recession and modification of the scarps. These conditions are in contrast to the generally pronounced erosion of the upthrown side of the Hite Fault, which, in most instances, has been striped to the level of the upland pediment of the Blue Mountains' slope. Although the faults in the Hite System are expressed topographically, they do not exhibit the primary control on topography that generally characterizes the Wallula Fault. Instead, the Hite and related faults are expressed largely by areas of differential erosion: aligned drainages, notches in ridges and spurs, or, locally, as fault line scarps, or "china walls" of cemented breccia. These contrasting geomorphic expressions strongly favor a younger age for the Wallula Fault System.

Second, some faults in the Wallula Fault System have demonstrated "young" motions, with a few faults offsetting loess, Touchet beds or colluvium (e.g. the Buroker and Wallula faults, or the Barrett Fault, south of Umapine, Oregon). We know of only one instance where a fault in the Hite System demonstrably cuts "young" materials: on the Thorn Hollow Fault between the Little Dry Creek and Bade faults south of the study area near Weston, Oregon (Kienle and others, 1979). However, this young movement is best interpreted as reactivation of part of the Thorn Hollow Fault between the two younger faults of the Wallula System, particularly in light of the marked absence of evidence for young movement on the Thorn Hollow Fault to the south. (Kienle and others, 1979).

Third, if the right-lateral Wallula Faults and right-lateral Hite Faults were the same age, but produced by different stresses, then one

should observe a transition area between the two sets of faults. However, faults in the Wallula System extend eastward to near the Hite Fault with no evident change in sense of motion or strike. Indeed, the Ben Day Gulch Fault appears to cross the north end of Hite Fault north of Pomeroy (Plate 3), while several small faults in the Wallula System cut the Hite Fault gouge zone several miles south of the study area near Tollegate, Oregon (Kienle and others, 1979). Thus, these observations also suggest that the Wallula and Hite systems are not the same age, and are consistent with a younger age for the Wallula System than for the Hite System.

The conclusion that the Hite Fault System is older than the Wallula Fault System is important to an understanding of the tectonic development of the area. It implies a change in orientation of the stress field in the area to account for the change with time of the orientation of the faults. More important to this analysis, however, the conclusion implies that only faults with motions compatible with the stress field which produced the Wallula Fault System need to be considered for evaluation of seismic hazard in the area. This is because faults in the Hite Fault System were a response to a stress field different from and older than that which has caused the motions on faults in the younger Wallula Fault System.

Several tectonic models of the area have been proposed to account for the previously-known geologic structures. At present, the available regional models (Glass, 1980; Laubscher, 1977; Davis, 1977; Rockwell, 1979) are general in scope and deal only with the pattern of regional structures and seismicity. More elaborate models are available for only limited parts of the Columbia Plateau; Walla Walla-Northern Blue Mountains (Kienle and others, 1979); Wallula Gap Fault (Farooqui, 1979); Yakima Ridges and the Cle Elum-Wallula Lineament (CLEW) (Laubscher, 1977; Kienle and others, 1977); and Pasco Basin (Rockwell, 1979).

All regional models postulate north-south compression of the areas west of the CLEW, consistent with the north-south shortening of that area by the generally east-west trending folds of the Yakima Ridges. In Newcomb's view (1970), most structures are adequately explained by north-south compression, coupled with subsidence of the large basins and uplift of the Cascades and Blue Mountains. However, the models of Glass (1980) and Laubscher (1977) also invoke slight rotation of the area southeast of the CLEW, and predict extensional faulting in the Walla Walla and LaGrande basins. The model presented by Glass (1980) is particularly attractive, in that it is consistent with detailed mapping by Gehrels and White (1980) in the La Grande area, by Kienle and others (1977) along the CLEW, by Farooqui (1979) of the Wallula Gap Fault, and by Kienle and others (1979) in the northern Blue Mountains-Walla Walla area. This model represents an improvement over earlier models (e.g. Laubscher, 1977; Davis, 1977) which concentrated on tectonics of the CLEW and areas to the southwest, particularly in that it accomodates the observed dextral-slip motion of the Hite Fault and pull-apart motion of the La Grande Graben (Gehrels and others, 1979; Kienle and others, 1979). The Glass (1980) model has two major flaws. First, it predicts extension across a north-northeast trending graben in the Eureka Flats area, and, second, it assumes that the Hite and Wallula fault systems are of the same age. This investigation has not confirmed a graben at Eureka Flats, and, indeed, has shown that the Frenchman Springs Basalt passes unfaulted across the supposed location of the graben's east boundary, near Lamar (T9N, R34E). As discussed above, the available data indicate that the Hite Fault System is older than the Wallula Fault System.

Elimination of the Eureka Flats "graben" and the Hite Fault System from consideration as products of the most recent tectonic regime allows construction of a tectonic model simpler than that proposed by Glass (1980). This model, illustrated in Figure 10, attempts to explain only the youngest and/or active structures, and is thus a neotectonic model. It does, however, share several features with the Glass (1980)

and Laubscher (1977) models. The model invokes north-south compression to account for observed right-lateral slip on the Wallula and related faults, shown on Figure 10 as the CLEW. Assuming that the Service Anticline and the Wallula Fault System are complimentary shears, the maximum compressive stress which produced them must be oriented aproximately NNW-SSE, between the strikes of the two structures, probably somewhat toward the Service Anticline, which exhibits compression, and somewhat away from the Wallula Fault System, which exhibit extension. Thus, the exact direction of the maximum compressive stress is more closely limited than in the Glass (1980) model by the new data showing a left-lateral compressive motion on the faulted, north-striking Service Anticline. The model also invokes a slight clockwise rotation of the block southwest of the CLEW, as do those of Glass (1980) and Laubscher (1977), to account for the change from extension across the CLEW in the southeast to compression across it in the northwest.

The motions involved are relatively small: we estimate less than a half mile (kilometer) of total right-lateral slip on the Wallula System near Milton-Freewater (Kienle and others, 1979), much less on the Service Anticline, and, based on paleomagnetic data, (Kienle, 1971), less than 2 or 3 degrees of rotation. Such small motions are clearly inadequate to produce the generally east-west striking Yakima Ridges (Figure 10) which involve crustal shortening of several miles (kilometers) (Laubscher, 1977). However, we envision that these folds, like the Hite Fault, were largely formed prior to establishment of the youngest tectonic regime. Detailed studies of the Columbia Hills and Horse Heaven anticlines shows them to have formed largely between 3.5 and 4.5 million years ago (Kienle and Newcomb, 1973). Small, apparently young deformation of some of the Yakima Ridges, such as those reported at Gable Mountain (Coombs, personal communication) and at Toppenish Ridge, south of Yakima, Washington, (Campbell, 1980) may, however, be a response to the tectonic regime postulated on Figure 10.

4. VICINITY GEOLOGY AND TECTONICS OF THE SIX DAM SITES

4.1 Lower Granite Dam

Lower Granite Dam is located on the Snake River between Wawawai and Almota in NE 1/4 sec. 32 and SE 1/4 sec 29 T14N, R42E, near the southeast margin of the Palouse slope (Plate 3). The dam foundation and abutments are located in flows of the lower part of the Grande Ronde Basalt ($Tygr_{n1}$, Swanson and others, 1977). The flows dip less than 0.5° NW and contain several local flow-top breccias. One such prominent flow breccia zone occurs in the left (south) abutment and has been treated with shotcrete.

The nearest major tectonic structures are the complex Lewiston structure 18 miles (29 km) to the south-southeast (out of the study ara) and faults on trend with the Hite Fault, 7 miles (11 km) to the southwest (Tps 12 and 13N, R42E). An unnamed northwest-striking fault is inferred to pass within 3 miles (5 km) west of the dam (Tps 13 and 14N, R42E). This fault appears to be at least 5 miles (8 km) long; its offset is not known. None of these faults show evidence of Holocene activity. The nearest faults which could have had Holocene activity are the Ben Day Gulch Fault, 13 miles (21 km) to the southwest, north of Pomeroy (T12N, R42E), and the Promontory Point Fault near Walla Walla, over 50 miles (81 km) away.

4.2 Little Goose Dam

Little Goose Dam is located on the Snake River about 10 miles (16 km) upstream of Lyons Ferry in T13N, R38E (Plate 2). The dam is founded in the upper part of the Grande Ronde Basalt (Tyg_{n2}) although the left (south) abutment is mantled by a large bar of glaciofluviatile gravel. Several small remnants of intracanyon Pomona and Elephant Mountain flows also occur above the south abutment. Attitudes of the basalt change from gently east-dipping to gently west-dipping across a series of small folds whose axes pass near the dam (Plate 2).

The nearest major fault is the Hite Fault which is within about 24 miles (39 km) southeast of the dam. The fault nearest to the dam

is the Mile 74 Fault, a small strike-slip fault 1.8 miles (2.9 km) upstream of the dam axis (Plate 3). Other nearby faults are the Lyons Ferry Fault, about 4 miles (6 km) downstream of the axis (Plate 2), and the Central Ferry Fault, 11-1/2 miles (19 km) downstream of the axis (Plate 2), and the Central Ferry Fault, 11-1/2 miles upstream (Plate 3, T13N, R40E); neither appears to have offset upper Pleistocene flood gravels (Qgf). However, the Central Ferry Fault may offset the Palouse loess at it's south end (Section 3.2.1.3). The Mile 74 Fault does not offset overlying colluvium. The nearest fault which may have had Holocene movement is the Ben Day Gulch Fault (Plate 3 T12N, R42E) 11-1/2 miles (19 km) to the southeast. The nearest major faults with Holocene motion are those of the Wallula Fault System near Walla Walla, about 40 miles (64 km) to the south-southwest.

4.3 Lower Monumental Dam

Lower Monumental Dam is located near the mouth of Devil's Canyon, on the boundary of Tps 12 and 13N, R34E (Plate 2). It is founded in the upper flows of the Grande Ronde Basalt ($Tygr_{n2}$), although both abutments are mantled by thick glaciofluvatile gravels. Touchet beds mantle the gravels downstream of the left abutment. The basalt flows are nearly horizontal, dipping to the west only a few feet per mile.

Two small northwest-striking faults occur in the right bank approximately 2,600 and 3,700 feet (793 and 1,129 m) downstream of the dam axis. These faults appear to cut only Grande Ronde ($Tygr_{n2}$) and Frenchman Springs flows; the overlying Roza and Priest Rapids members are apparently not offset. The nearest significant fault is the northwest striking Burr Canyon Fault, 5 miles (8 km) downstream (sec 24 T12N, R33E). This fault extends 15 miles (24 km) southeast to near Clyde (Plate 2); however, it does not offset glaciofluvatile gravels. The nearest faults with possible Holocene motion are those of the Wallula Fault System approximately 37 miles (60 km) to the south.

4.4 Ice Haroor Dam

Ice Harbor Dam, located on the Snake River approximately 9 miles (14 km) upstream of its confluence with the Columbia River (Plate 2, T9N, R31E), is founded in the Elephant Mountain and Pomona flows. Ice Harbor flows are present on both abutments, and Ice Harbor dikes occur both up and downstream of the axis. A series of small, complex folds parallel the dikes and may be genetically related to them (Swanson and others, 1975). Glaciofluvatile gravels (Plate 2) partially mantle both abutments and the surrounding uplands.

Faulting of unknown extent was reported in foundation test holes and excavations, southwest of the dam centerline (USCE letter, 1980). These faults were not observed in either bank during this investigation; however, outcrops are not adequate to rule out their presence. The nearest faults with probable Holocene offset are those of the Wallula Fault System, 12 miles (19 km) to the south-southeast (Rattlesnake Wallula Lineament, Plate 2, T7N, RS30 and 31E).

4.5 Mill Creek Dam

Mill Creek Dam is a flood control dam located south of Mill Creek, 1 mile (2 km) east of Walla Walla on Prospect Point Ridge (corner secs. 23, 24, 25 and 26, T7N, R36E). The dam is founded in "old" (Pleistocene) "gravels and clay" (Qg) of Newcomb (1965), and partially in Frenchman Springs or Dodge member basalts. The site is completely mantled by loess, so details are known only from drillhole data and foundation excavations.

Prospect Point Ridge is bounded both north and south by faults (Plate 2); thus, faults occur quite near the dam. The Prospect Point Fault is inferred to pass about 1-1/2 miles (2 km) north of the dam, while the Promontory Point Fault passes approximately 1-1/4 miles (2 km) to the south. The "Buroker faults", which are apparently related to the Promontory Point Fault, are about 1-1/3 miles (2 km) to the southeast. As discussed in Section 3.2.2.9, one of the "Buroker faults" cuts loess of post-Touchet age, and is considered to have undergone Holocene movement.

4.6 McNary Dam

McNary Dam is located on the Columbia River 2 miles (3 km) upstream from Umatilla (Plate 1, T5N, R28E). The dam is founded in Umatilla and Priest Rapids flows, which locally have a tuffaceous interbed between them. Glaciofluviatile gravels occur in the river channel and on the abutments. Attitudes in the basalt vary from gently northwest to southeast across a series of small folds (Plate 1).

The dam axis lies 1 mile (1.6 km) east of the axis of the Service Anticline. Although a major fault is locally exposed along the anticlinal axis, motion on the structure appears to predate the glaciofluvatile gravels (Qgf), as discussed in Section 3.2.3. A small thrust fault discovered in the dam foundation during exploratory work for construction, appears to extend northeast into a fault on the north bank, 1 mile (1.6 km) upstream from the right abutment. This fault is mantled by apparently undisturbed upper Pleistocene glaciofluvatile gravels, although exposures of the fault-gravel contact are lacking. The closest fault which has apparently undergone late Pleistocene or Holocene offset is the small, northwest-striking fault exposed in a borrow pit 2 miles (3 km) north-northwest of the dam (NE 1/4 NW 1/4 sec 33, T6N, R28E), which, as discussed in Section 3.2.3, appears to be related to the Service Anticline.

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APPENDIX A

A.1 Scope of Investigation

The investigation included a review of previous studies, compilation of preliminary geologic and photo lineament maps, preparation of an interim report (Task 1 report), field reconnaissance of the area, detailed studies of selected faults and of the immediate vicinity of each dam, and preparation of a final report with reconnaissance geologic and tectonic maps. The area investigated (Figure 1) includes parts of the Pendleton, Oregon, and Walla Walla and Pullman, Washington, 1° x 2° Army Map Service topographic sheets. For the purposes of mapping, the project area was divided into four sub-areas, including: 1) the lower Snake River corridor; 2) the Hite Fault area; 3) the Service Anticline; and 4) the Walla Walla-Mill Creek area.

The investigation was conducted in three phases. Phase I consisted of plotting of linears from previous investigations of the area (Rockwell, 1979; Glass, 1980; Slemmons and O'Malley, 1980) onto 7-1/2 minute and 15 minute quadrangles for field use in Phase II, and evaluating and prioritizing these linears for field investigation. Also included in Phase I was the compilation of preliminary reconnaissance scale geologic and tectonic maps.

Phase II of our investigation was devoted to mapping the Hite Fault, the lower Snake River corridor, the Service Anticline, and in the Walla Walla-Mill Creek area. Detailed studies of selected geologic features were also conducted.

Phase III of the investigation included preparation of final maps and this final draft report. This report presents the results of the three phases, along with an analysis of the new data on faulting in the study areas.

A.2 Methods of Investigation

For Phase I studies, surficial geology, known faults and fold axes were compiled and transferred onto 1:250,000 scale maps for the Phase I report, and onto USGS 7-1/2 minute (1:24,000) and 15-minute (1:62,500) quadrangle maps for field checking during Phase II. Surficial geology and known teconic structures were compiled from geologic maps by Newcomb (1965, 1970), Kienle and Newcomb (1973), Rigby and others (1979), Swanson and others (1977, 1979a), Kienle and others (1979) and Slemmons and O'Malley (1980).

Linears were compiled from studies by Sandness and others (1979), Glass (1980) and Slemmons and O'Malley (1980), and supplemented by some additional linears from our consultant, R. Lawrence. Obvious cultural features were not included in the compilation.

Priorities were assigned to mapped linears by interpretation of various types of remote sensing imagery, including SLAR, LANDSAT, infrared imagery and Panchromatic aerial photographs. These included 1:80,000, black and white U-2 imagery of the entire area (Battelle, 1978), 1:12,000 black and white SLAR imagery of the damsites on the Snake and Columbia Rivers (USACE, 1979a); 1:250,000 black and white radar mosaic (east- and west-looking) for Walla Walla, Washington (USACE, 1979b); 1:80,000 false-color infrared of the Walla Walla and Pendleton AMS sheets (NASA, 1973); and 1:80,000 color transparencies of part of the Walla Walla and Pullman areas (Battelle, 1978).

The priority values referred to the apparent tectonic significance of various linear features in the study area, and were used as a guide for ground study of the features. The prioritization system was described and the prioritized linears were presented in the Interim Report.

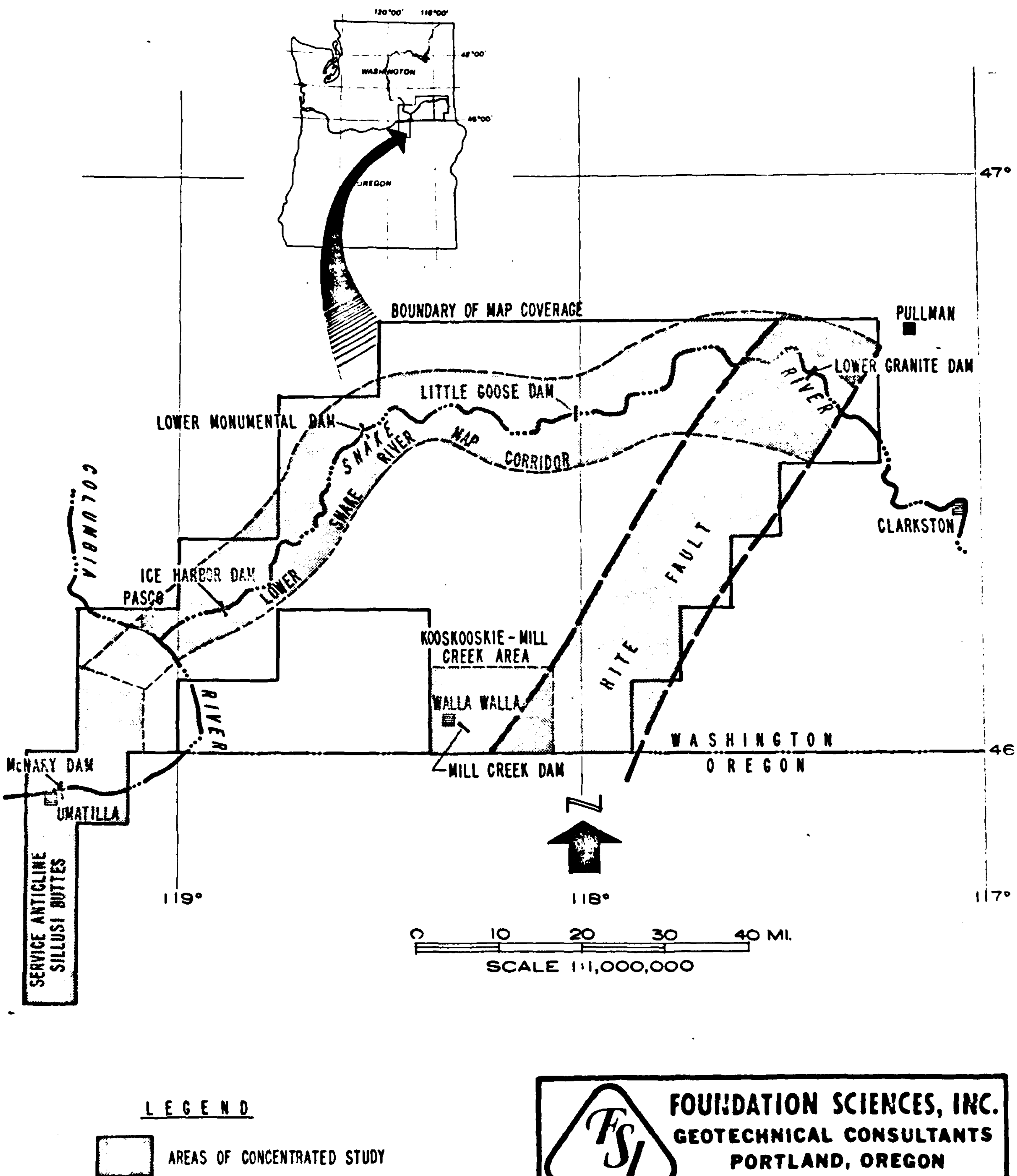
Reconnaissance mapping (Phase II) was accomplished in three parts, described in the Interim Report. They were: 1) construction of a preliminary field map to confirm the general stratigraphy of the area,

to aid in the identification of structures and to act as a basis for studies of regional tectonic history; 2) preliminary field checking of known structures and priority 1 and 2 linears in the basalt, and reconnaissance mapping of the sediments covering the basalts; and 3) detailed field checking of the faults and linears of particular importance, as determined during Part 2. During field work, the basalt stratigraphy described by WPPSS (1977) and Swanson and others (1979) was employed.

A.3 Acknowledgments

Field work for this project was conducted by C. F. Kienle, Jr., M. L. Hamill, K. E. Lite, and G. L. Peterson; the aerial photography interpretation was conducted by C. A. Nelson, assisted by our consultant, R. Lawrence. The geologic and tectonic maps were drawn by P. M. Kelly. Consultations with R. C. Newcomb and R. Lawrence, were of material assistance to us in our interpretation of the tectonics of the area.

Special thanks are due R. Anderson of the Washington Department of Energy in Spokane for assistance in obtaining driller's logs in Walla Walla County, Washington.



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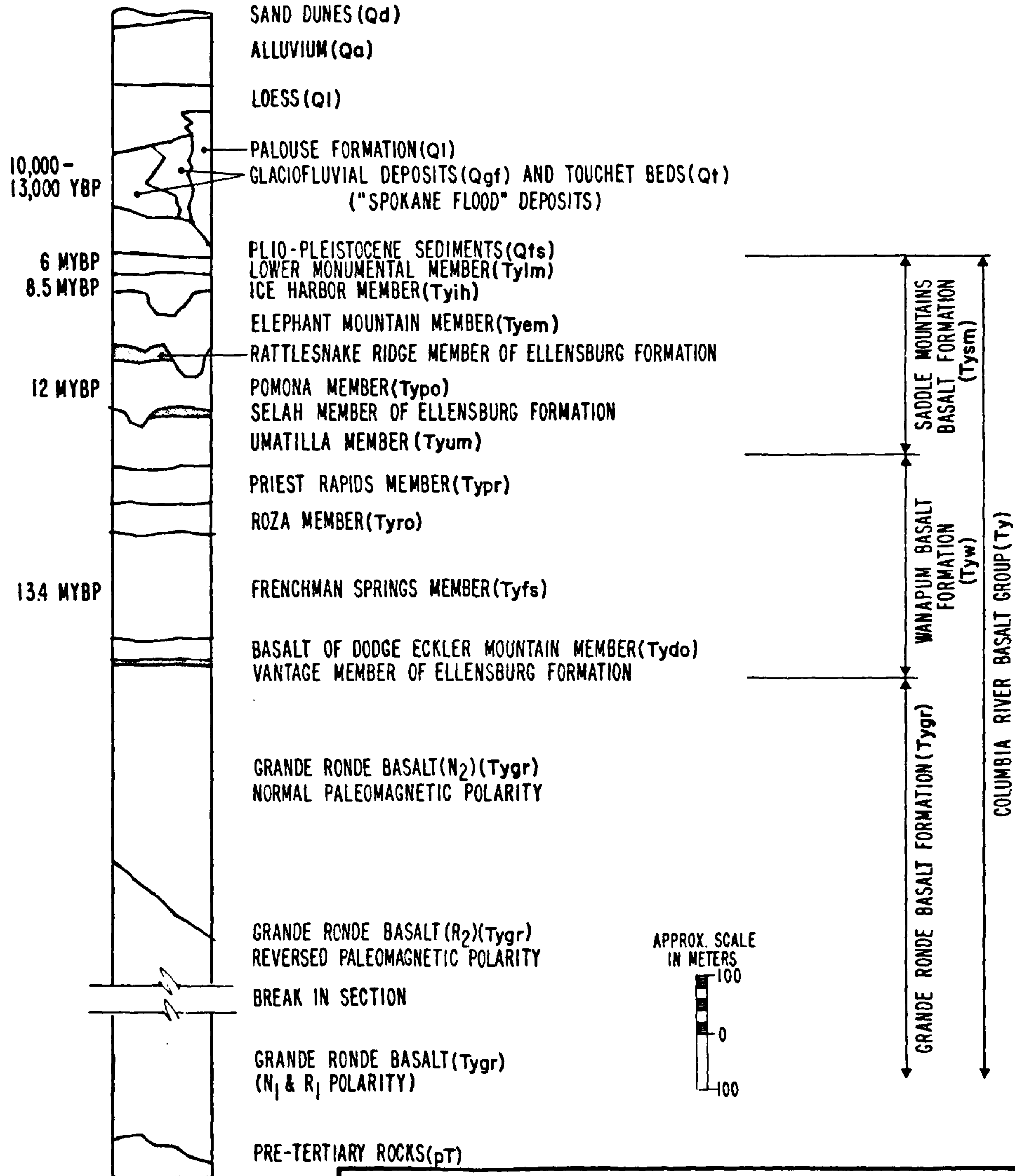
LOCATION MAP

DATE 8/11/80 **JOB NO.** 148-1 **FIG.** 1



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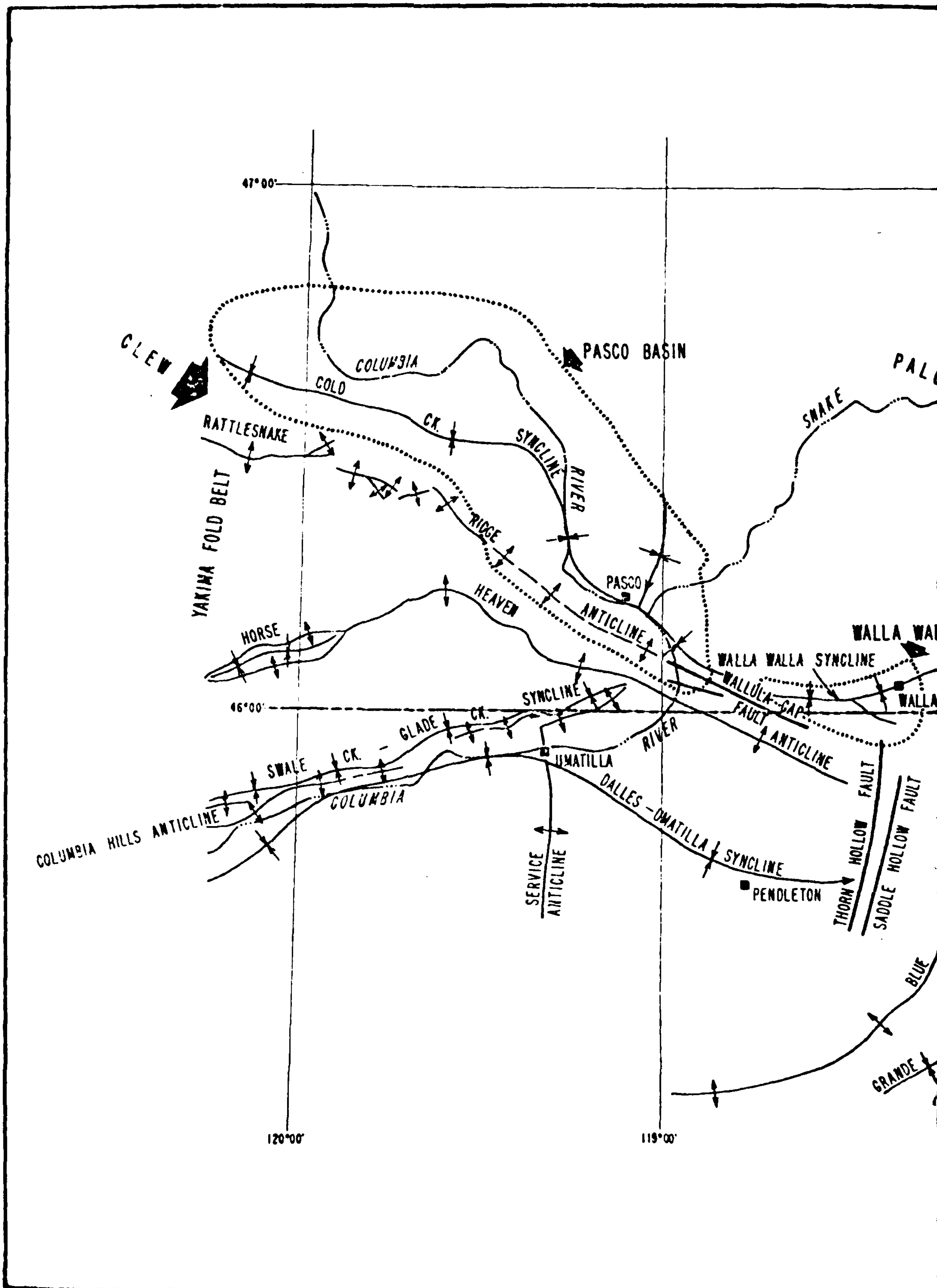
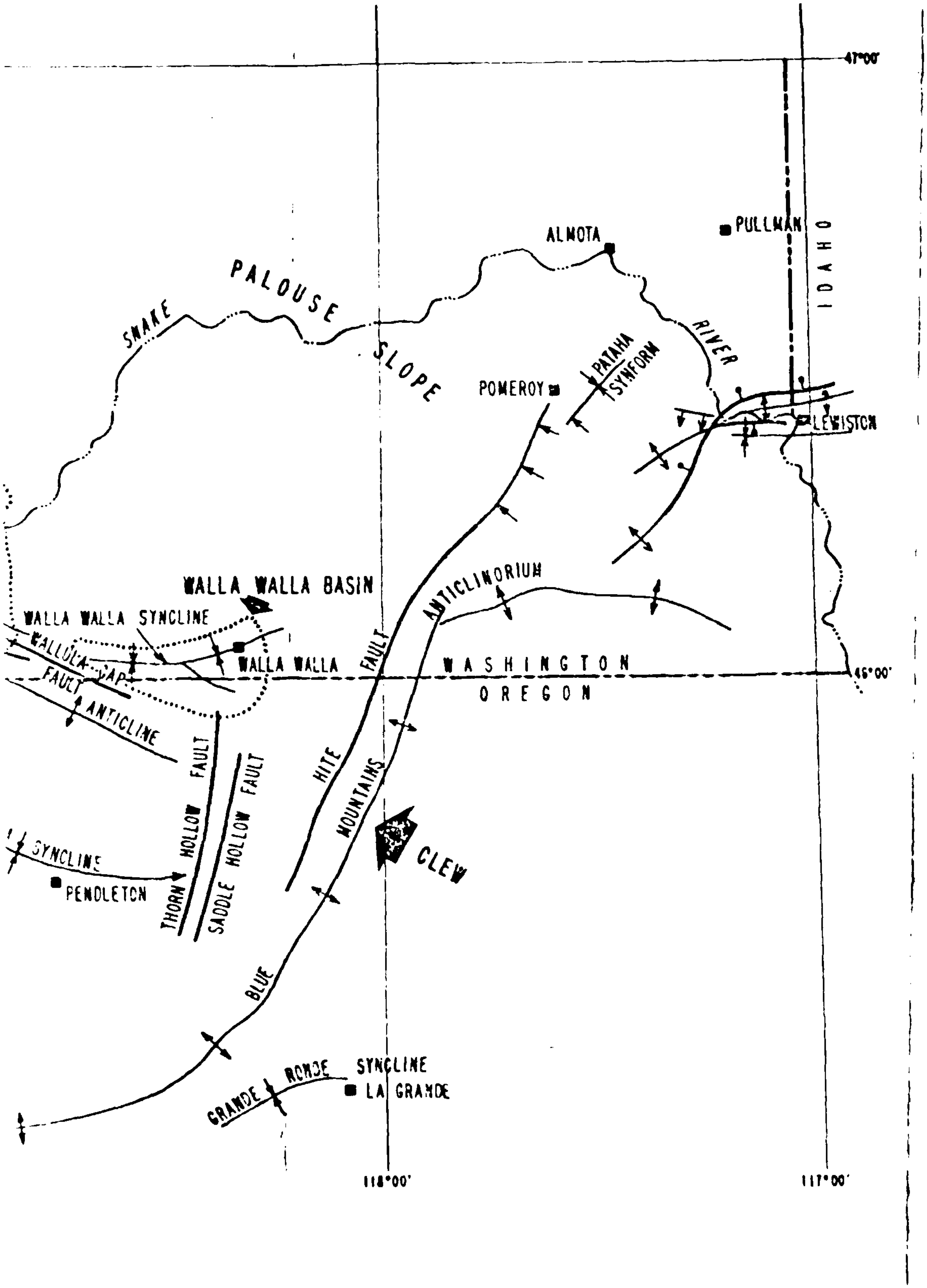
ENGINEERS
GEOLOGISTS

GENERALIZED STRATIGRAPHIC COLUMN

DATE NOV. 1980 DRN. SCALE 1 CM.-100 M FIG. 2



47°00'
46°00'
120°00'
119°00'
CLEW
PASCO BASIN
PAL
COLUMBIA
COLD
CK.
SYNCLINE
RIVER
RATTLESNAKE
YAKIMA FOLD BELT
RIDGE
SNAKE
PASCO
HEAVEN
HORSE
ANTICLINE
WALLA WA
WALLA WALLA SYNCLINE
WALLULA GAP
FAULT
ANTICLINE
WALLA
SYNCLINE
CK.
GLADE
SWALE
CK.
UMATILLA
RIVER
COLUMBIA
COLUMBIA HILLS ANTICLINE
DALLES - UMATILLA
SYNCLINE
SERVICE ANTICLINE
PENDLETON
THORN HOLLOW FAULT
SADDLE HOLLOW FAULT
BLUE
GRANDE



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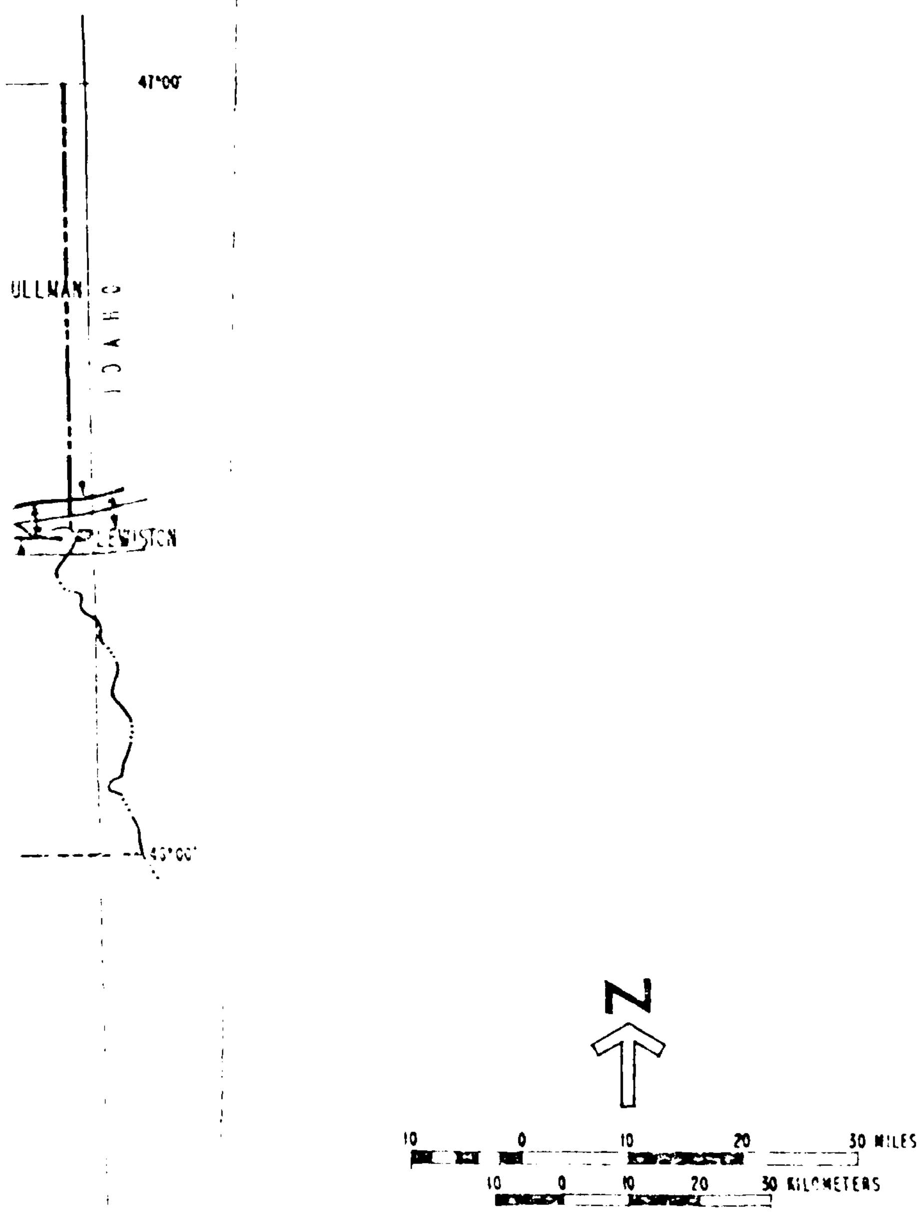

MODIFIED FROM NEWCOMB(1970)

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REGIONAL TECTONIC MAP

DATE NOV 1979 **JOB NO.** 148-1 **FIG.** 3

3

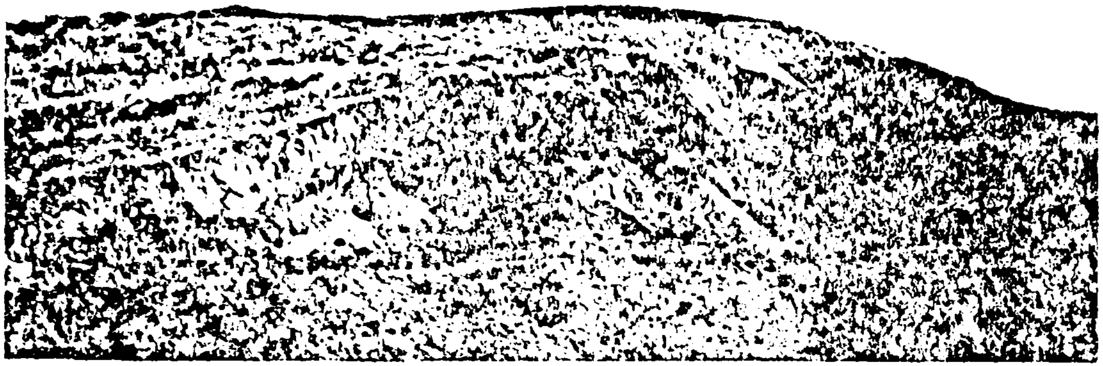

Figure 4A. VIEW OF FINLEY QUARRY LOOKING EAST-SOUTHEAST

Umatilla Basalt is in faulted contact with tectonic breccia and pre-Spokane flood colluvium in the fault zone on the left.

Location: NW¼ SW¼ NE¼ sec. 3, T7N, R30E

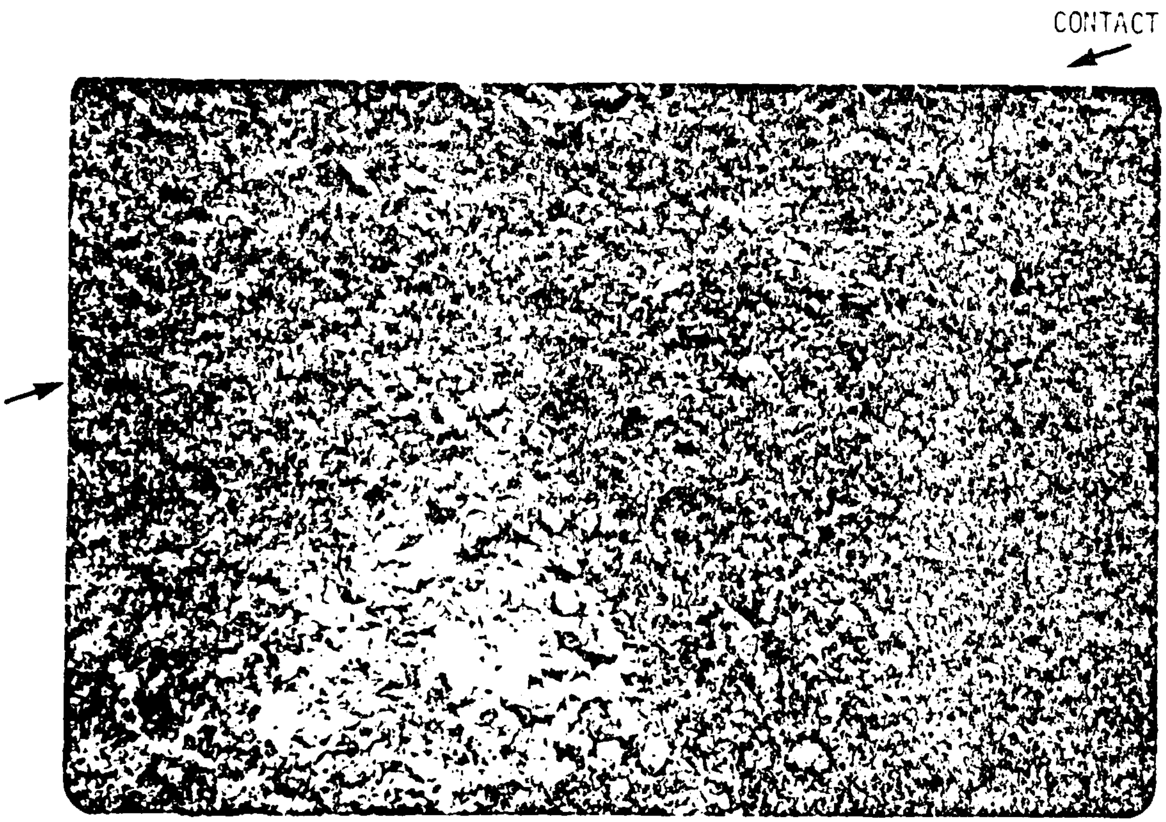

Figure 4B. CLOSE UP VIEW OF FAULT IN Figure 4C

Fault scarp colluvium on right is juxtaposed across fault, with caliche-rich, loess matrix colluvium on left. Both units lack clast assemblage and characteristics of Spokane flood gravels and are inferred to be pre-Spokane flood in age. Unfaulted overlying colluvium unit contains Spokane flood clast assemblage and is of post-Spokane flood age. Note large-wavelength, near-horizontal undulations in fault plane.

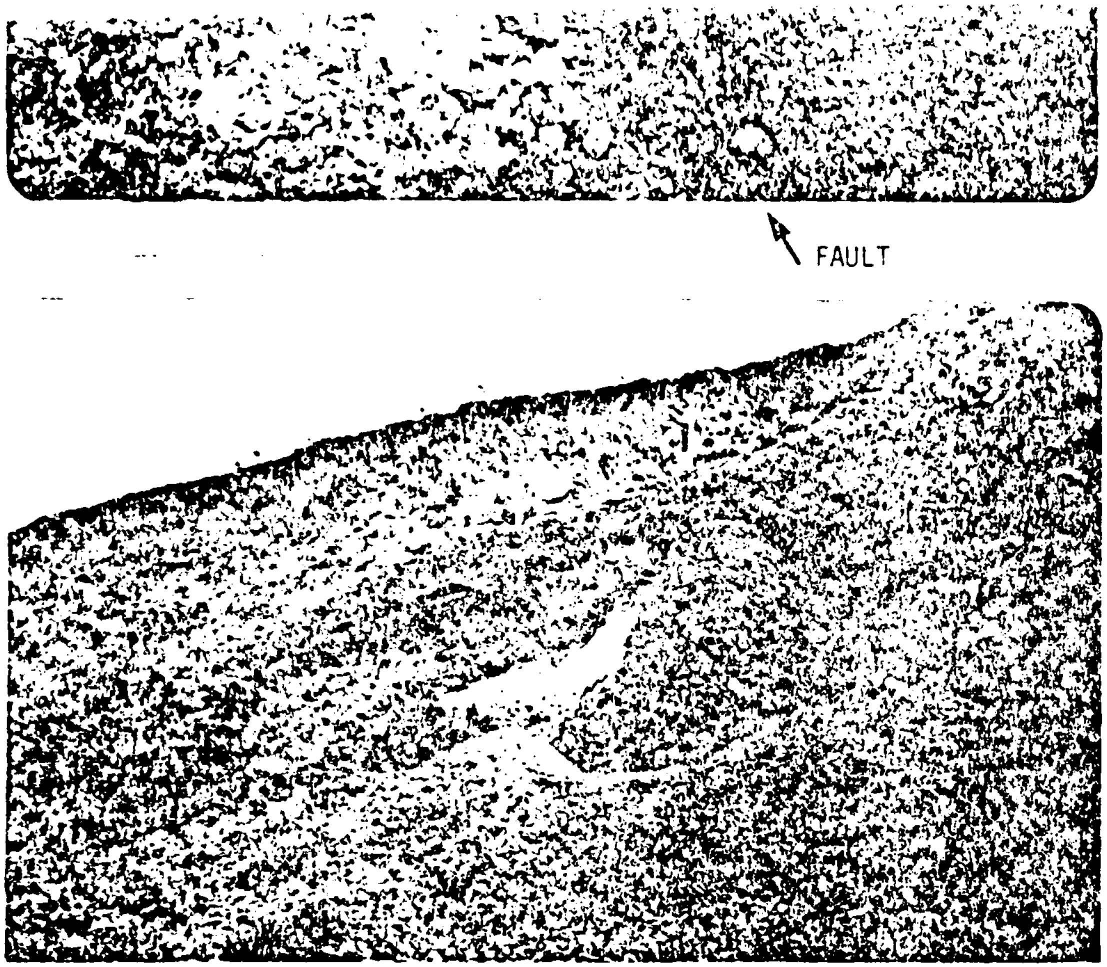

Figure 4C. (at left) FINLEY QUARRY FAULT ZONE
(Illustrated in sketch below.)

Figure 4D. (below) SKETCH OF FINLEY QUARRY FAULT
Note unfaulted post-flood colluvium and loess overlying older faulted materials. (Drawn same scale as photo 4C.)

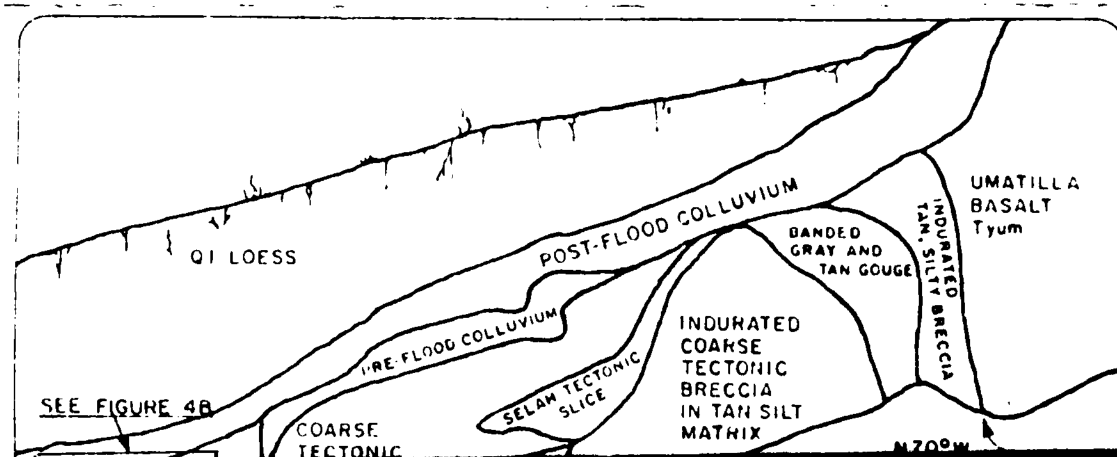

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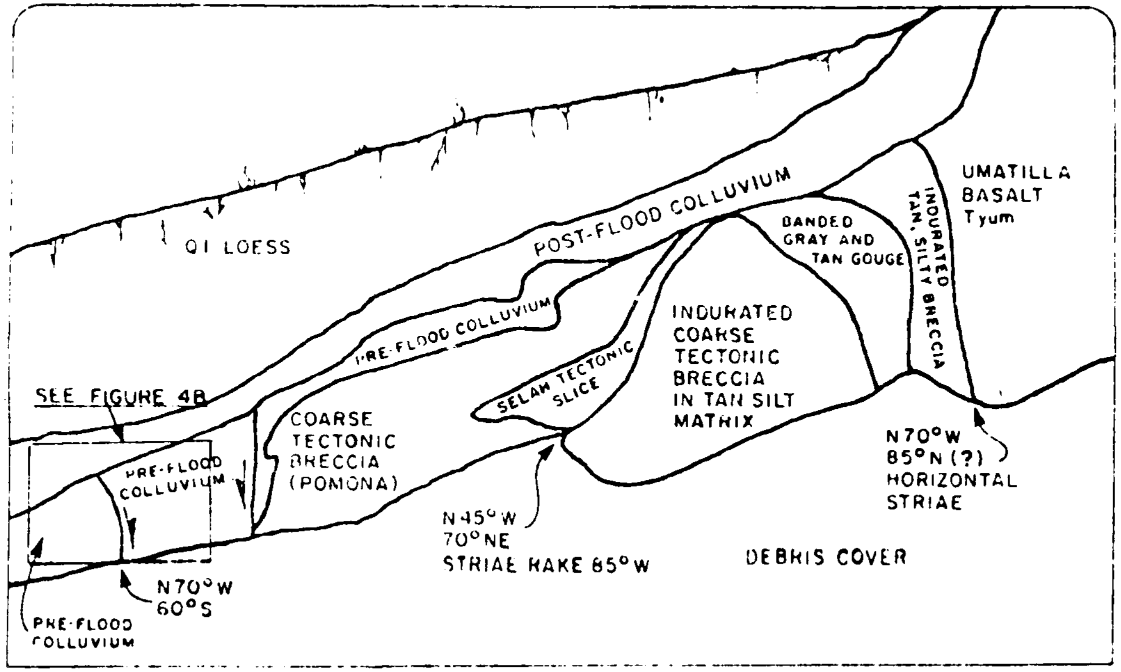
Figure 4D. (below) SKETCH OF FINLEY QUARRY FAULT
Note unfaulted post-flood colluvium and loess overlying older faulted materials. (Drawn same scale as photo 4C.)



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FINLEY QUARRY FAULT

DATE 12/80	**JOB NO.** 148-1	**FIG.** 4

ROZA FLOW

BRECCIA

UPPER:
Roza flow on left, tectonic breccia on right. Note caliche seam at edge of shear. Looking east-southeast.

SECONDARY FAULT

LEFT: High-angle, reverse, secondary shear cuts both basalt and caliche-impregnated colluvium (upper left). Looking N80°E. Loess is modern and rests on old road bed exposed at top of cut.

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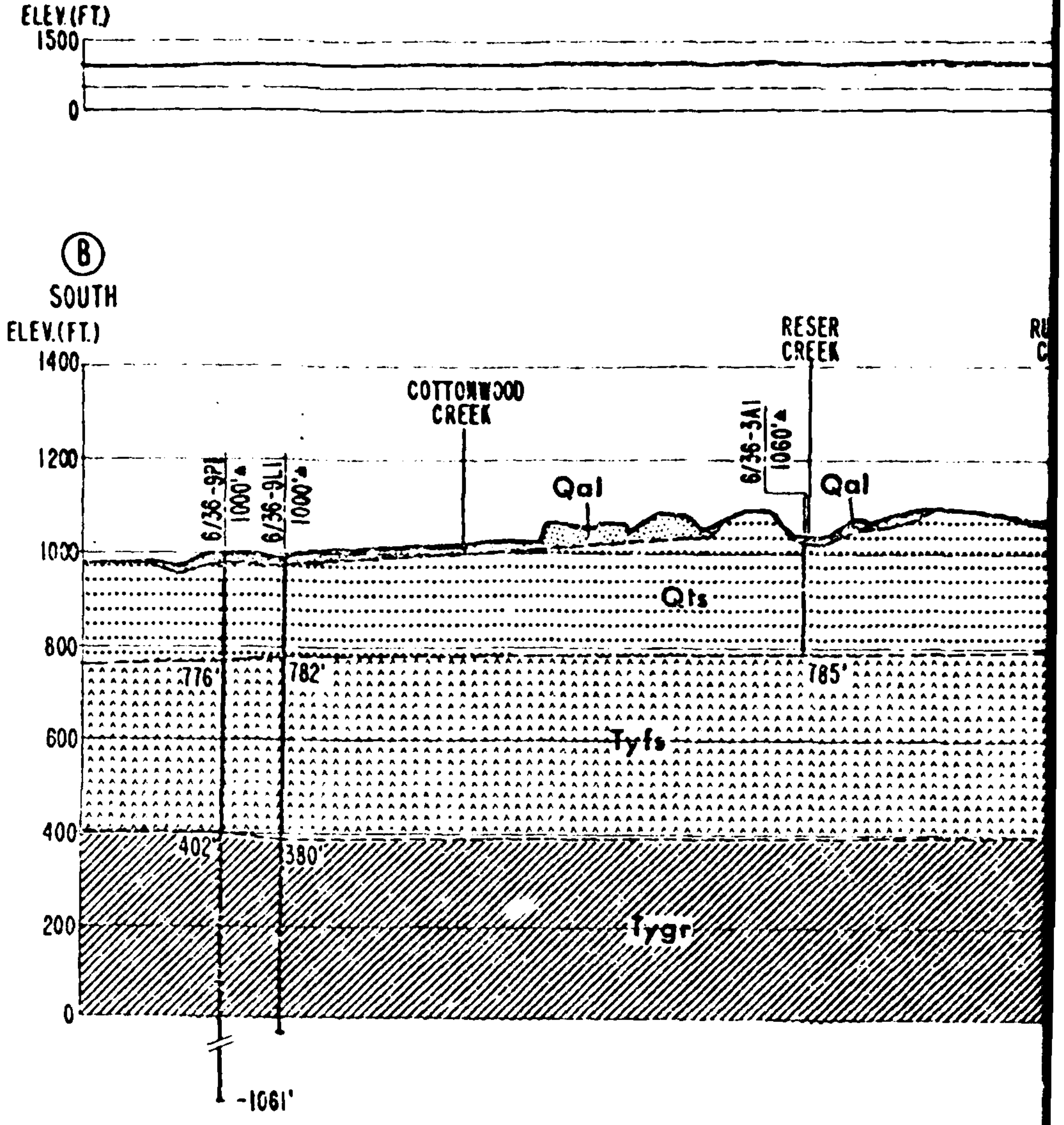
BEN DAY GULCH FAULT

DATE 12/80 **JOB NO.** 148-1 **FIG.** 5



LEGEND

FAULT

6/36-9P1 1000' WELL WITH LOCATION (FROM NEWCOMB, 1965): I.E. T6N, R36E, SEC. 9, SURFACE ELEV.-1000'

0 1/2 1

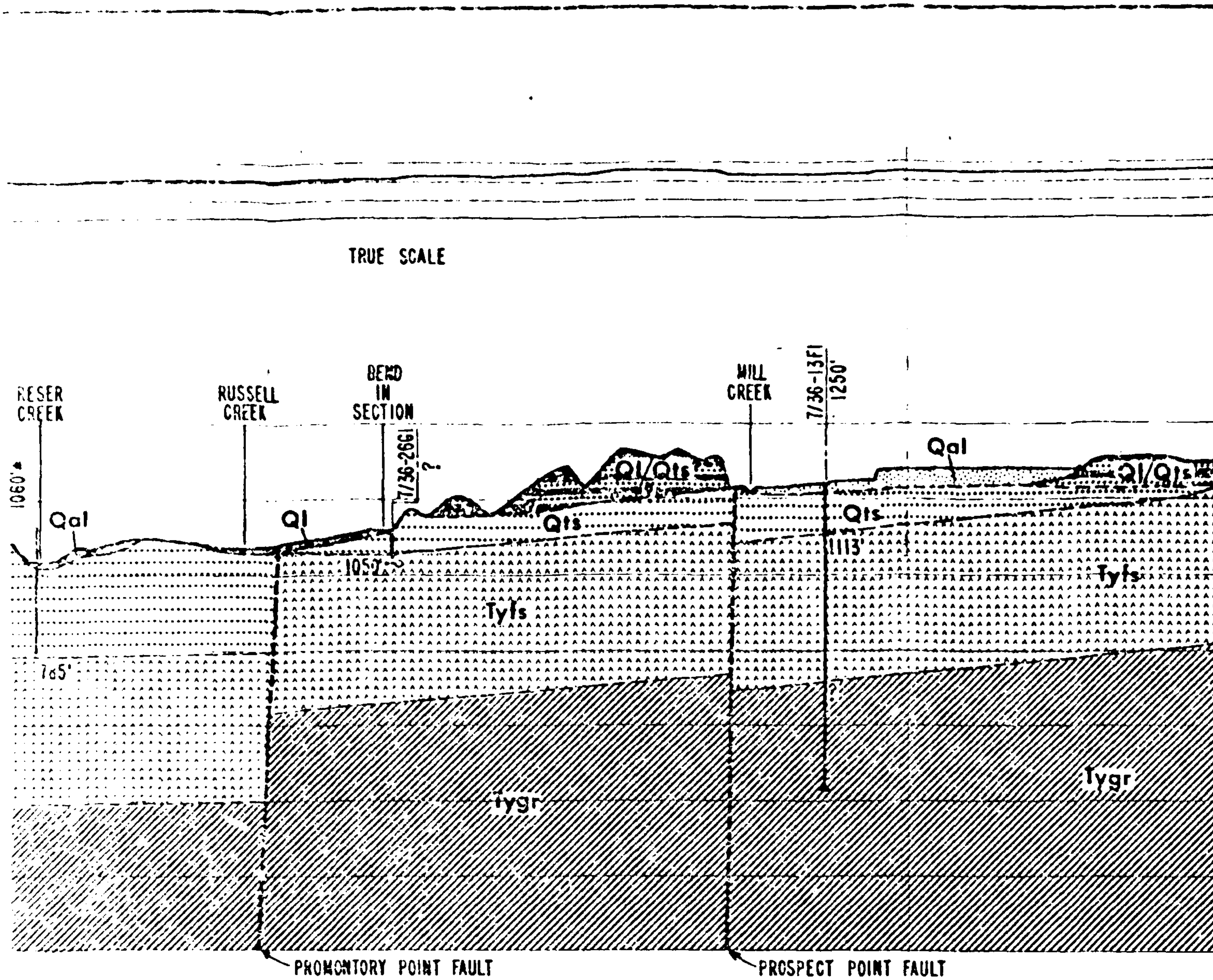
SCALES

VERTICAL: 1

HORIZONTAL: 1

VERTICAL EXAGGERA

REFER TO PLATE 2 FOR LOCA



1/2 1 2 MI.

SCALES

VERTICAL: 1" = 400'
HORIZONTAL: 1" = 4000'
VERTICAL EXAGGERATION: 10X

.FER TO PLATE 2 FOR LOCATION OF SECTION

UTM COORDINATES (METERS)

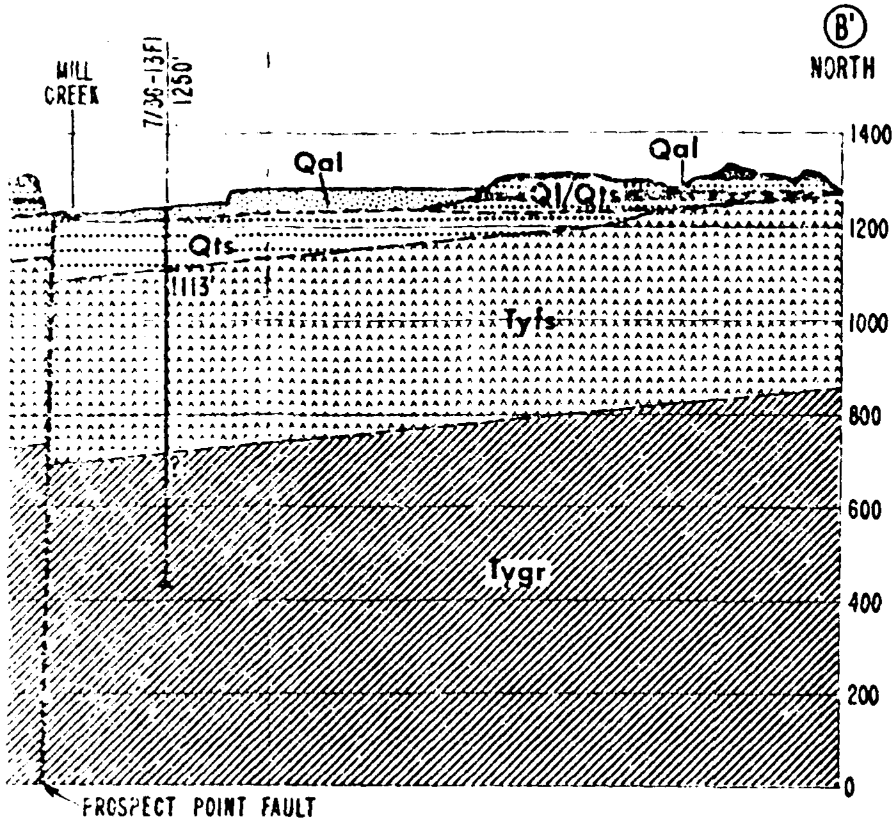
BEGINNING: 5,094,830 N 397,660 E
BEND IN SECTION: 5,100,810 N 401,510 E
END: 5,108,250 N 404,480 E

FOUND
GEOTE
P

PROSPECT
GEOLOGIC

DATE NOV. 1980 JOB

(2)



(METERS)
337,660 E
,810 N 401,510 E
430 E

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PROSPECT POINT RIDGE
GEOLOGIC CROSS SECTION
B-B'

DATE 1980	JOB NO. 148-1	FIG. 6

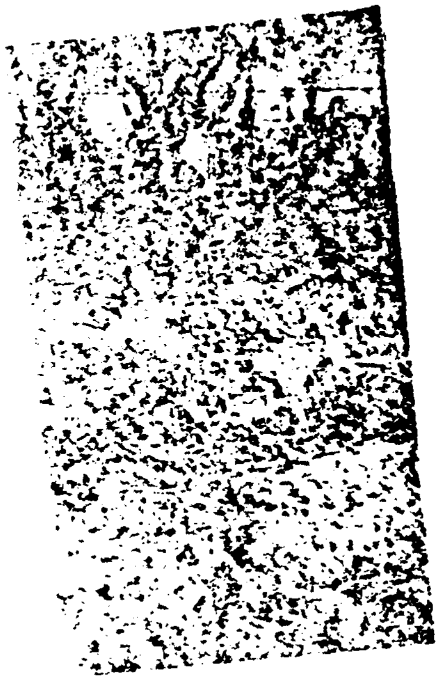
3

Figure 7A. BUROKER FAULT

View looking north on Russell Creek Road exposing old loess, fluvial gravel and Dodge flow (Eckler Mountain Member) cut by fault. Overlying young loess is not affected by faulting.

Figure 7C. CLOSE-UP OF FAULT

Tectonic breccia overlain by gravels and brown loess (Palouse?) on left; Dodge flow (lower left) overlain by gravels on right of fault. Note large subangular boulder of Dodge Basalt near center.



··ek Road exposing old
(ickler Mountain Member)
is not affected by faulting.

FAULT

ivels and brown loess (Palouse?)
riain by gravels on right of
of Dodge Basalt near center.

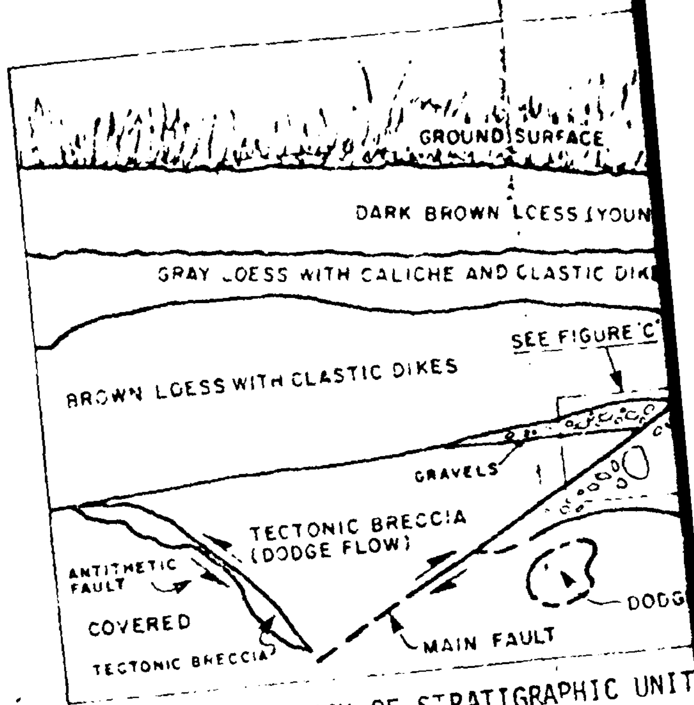


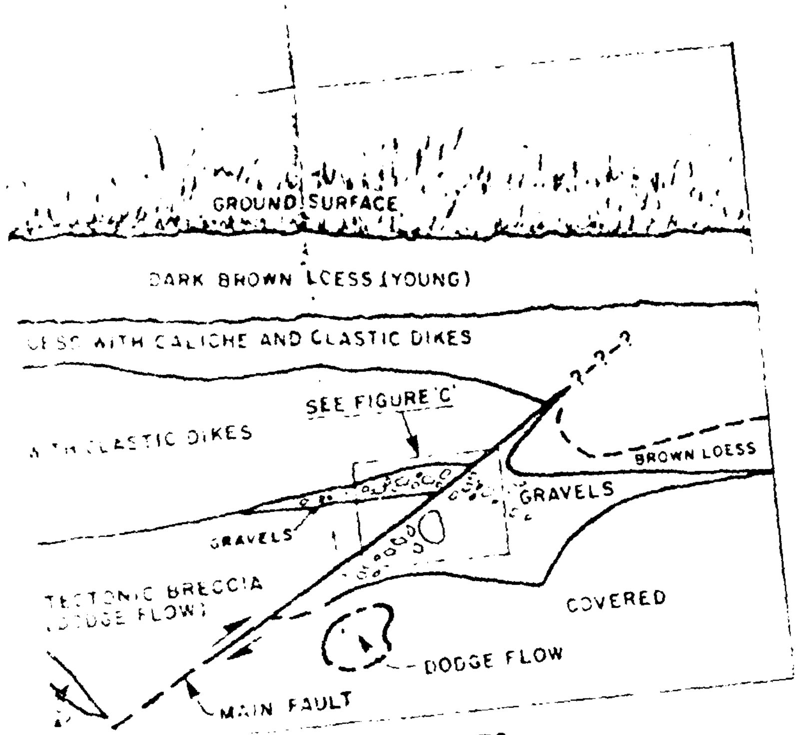
Figure 7B. SKETCH OF STRATIGRAPHIC UNIT
Units present in Buroker Fault expo
(same scale as photo 7A.)

Location: NW¼ SW¼ sec. 31, T7N, R37E

Strike: N15°E

Dip: 31°NW

Striae: Rake N30°W



SKETCH OF STRATIGRAPHIC UNITS
present in Buroker Fault exposure with faults shown
ale as photo 7A.)

¼ SW¼ sec. 31, T7N, R37E

e N30°W

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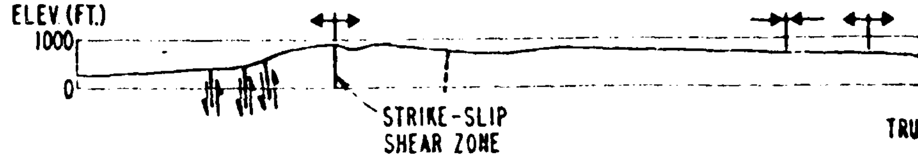
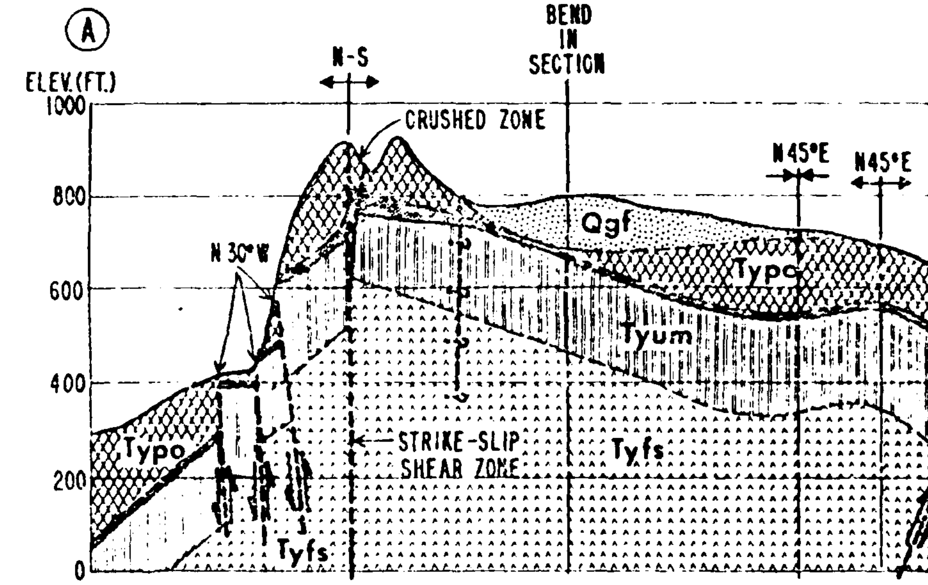
PORTLAND, OREGON

BUROKER FAULT

DATE 12/80 **JOB NO.** 148-1 **FIG.** 7

3





UTM COORDINATES (METERS)

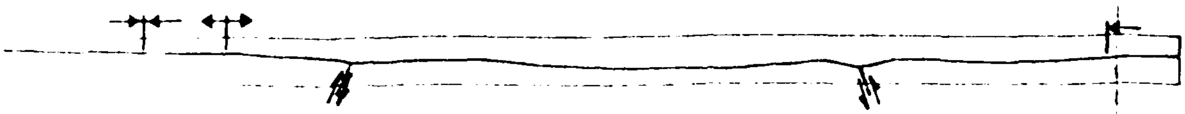
BEGINNING: 5,089,380 N 319,800 E
BEND IN SECTION: 5,091,010 N 321,370 E
END: 5,089,905 N 329,220 E

0 1/2 1

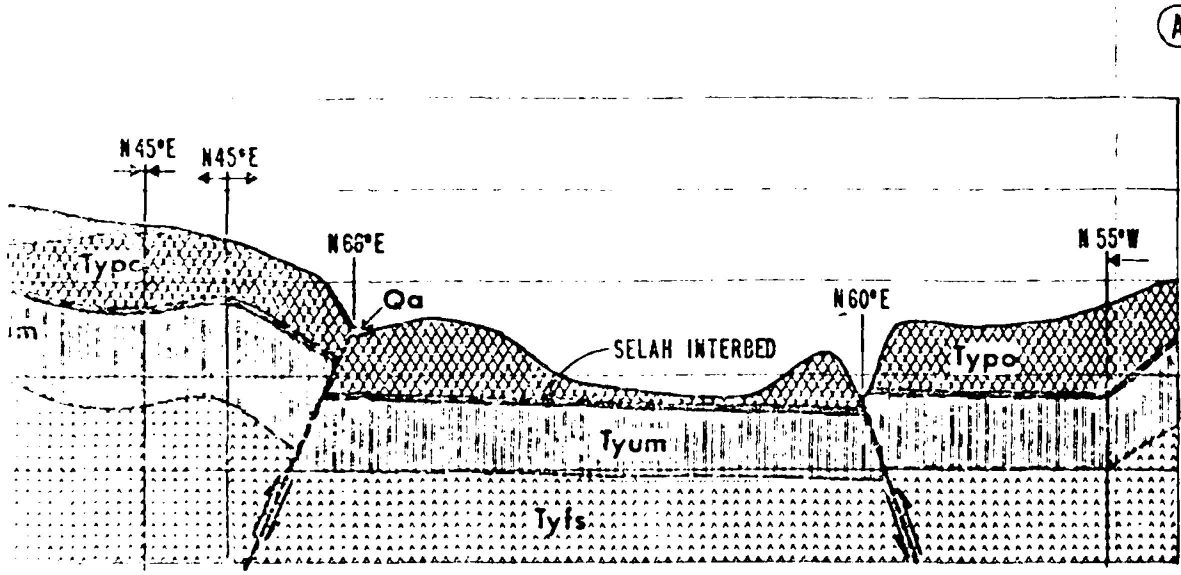
SCAL

VERTICAL
HORIZONTAL
VERTICAL EXAG

REFER TO PLATE 1 FOR

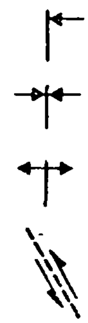


TRUE SCALE



SCALES
VERTICAL: 1" = 400'
HORIZONTAL: 1" = 4000'
VERTICAL EXAGGERATION = 10X

REFER TO PLATE 1 FOR LOCATION OF SECTION

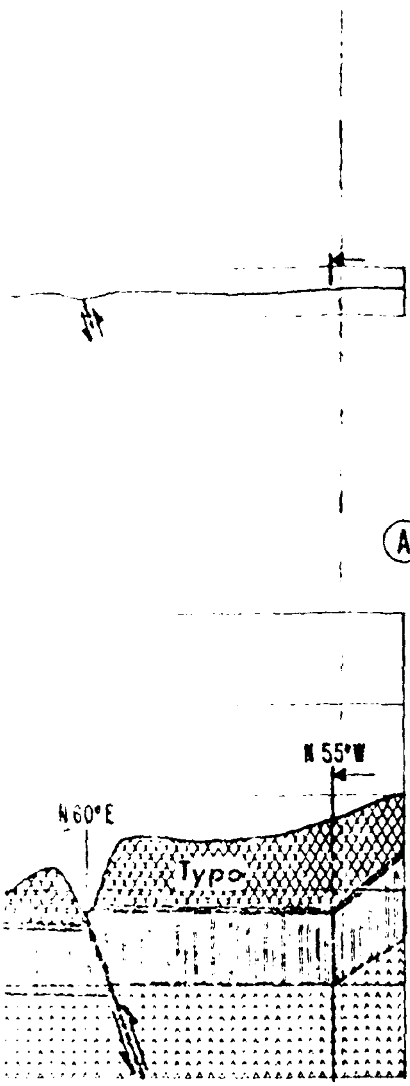


FOUND
GEOTEC
P

SILL
GEOLOGIC

DATE NOV. 1980 JOB

2



MONOCLINE AXIS WITH STRIKE

SYNCLINE AXIS WITH STRIKE

ANTICLINE AXIS WITH STRIKE

FAULT WITH RELATIVE SENSE OF MOTION AND STRIKE

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GEOTECHNICAL CONSULTANTS
PORTLAND, OREGON

SILLUSI BUTTE
GEOLOGIC CROSS SECTION
A–A'

NOV. 1980 JOB NO. 148-1 FIG. 8

3

Figure 9A. POSSIBLE HOLOCENE (?) FAULT IN BASALT BOULDER

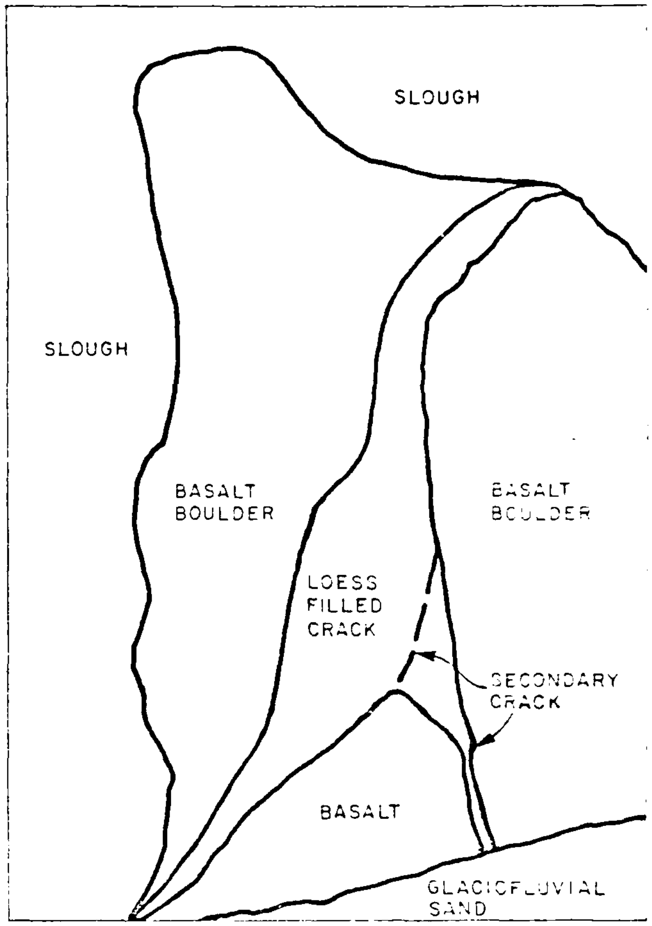

Figure 9B. SKETCH OF BASALT BOULDER (same scale as photo 9A)

Vertical loess-filled crack in a basalt boulder within a glaciofluvial deposit located on strike with a NW-trending, vertical, strike-slip fault. The fault, exposed in the east wall of the quarry, was not exposed beneath the glaciofluvial material.

Location: NE¼ SE¼ SW¼ sec. 28,T6N, R28E
Elevation 830'±

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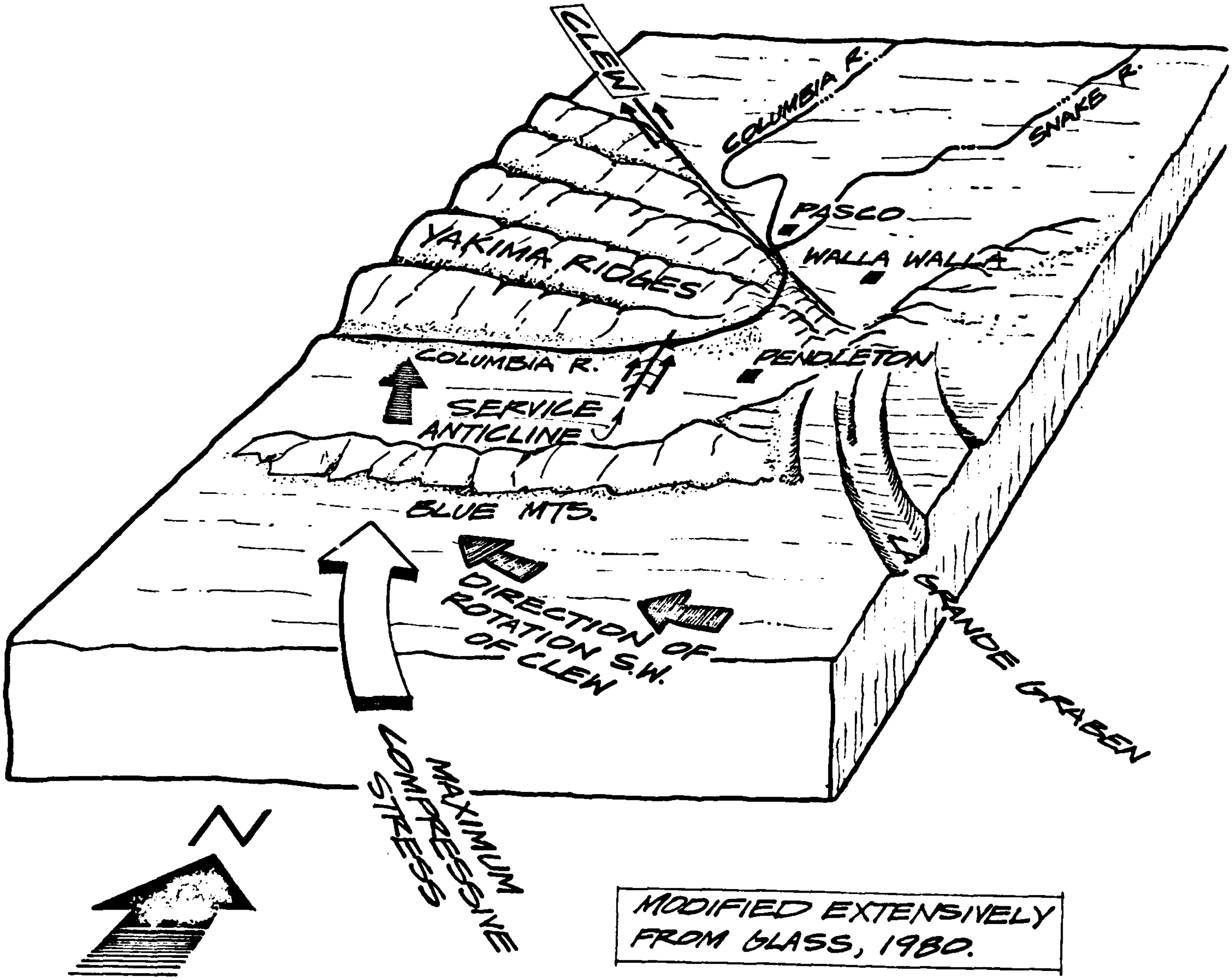
PORTLAND, OREGON

HOLOCENE (?) FAULTING
SERVICE ANTICLINE

DATE 12/80	JOB NO. 148-1	FIG. 9



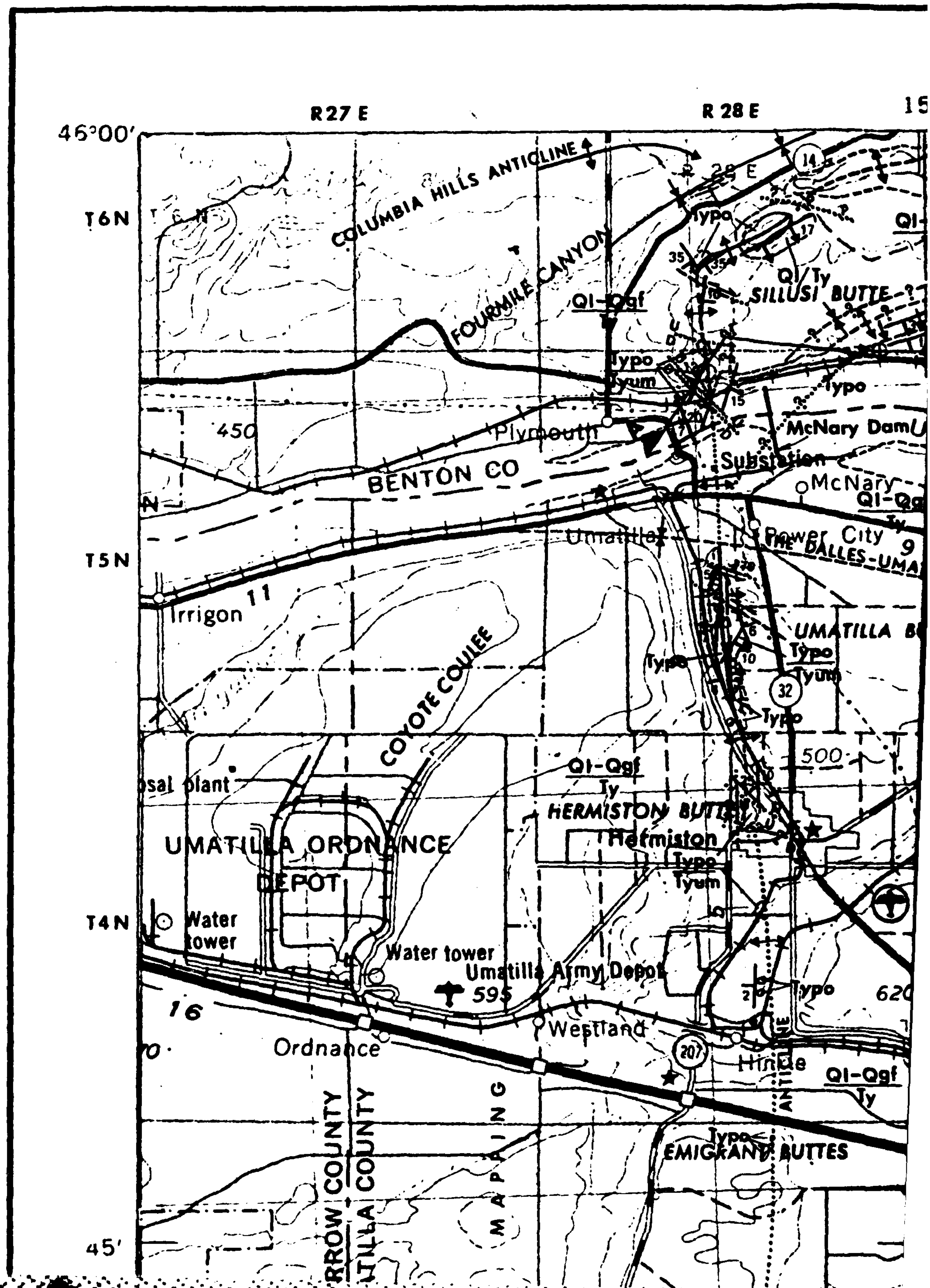
MODIFIED EXTENSIVELY FROM GLASS, 1980.

FOUNDATION SCIENCES, INC.
PORTLAND, OREGON

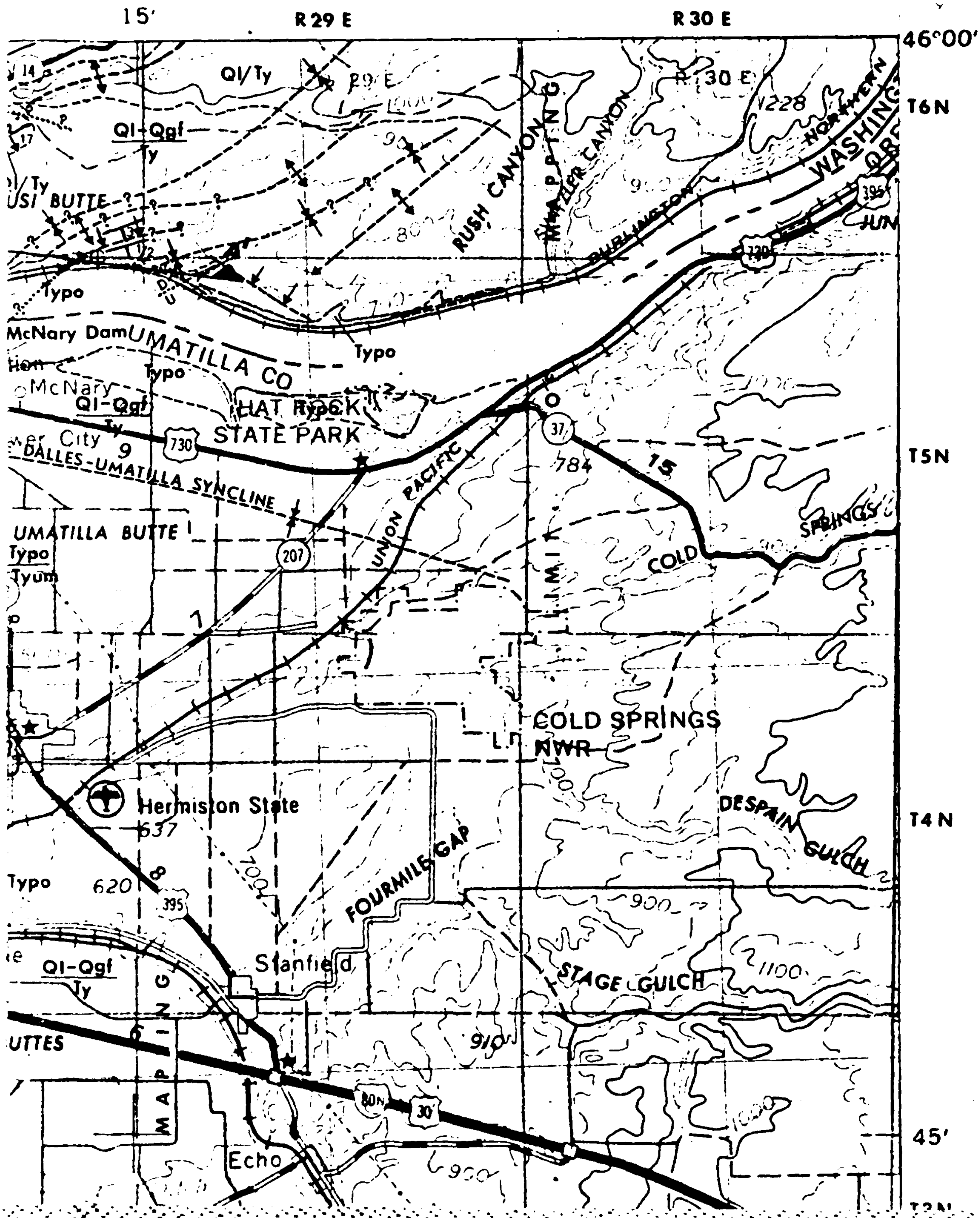
ENGINEERS
GEOLOGISTS

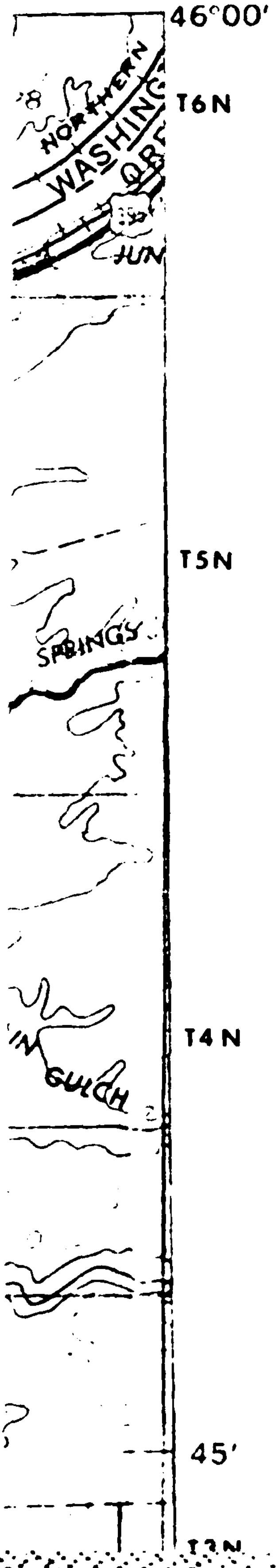
NEOTECTONIC MODEL
CENTRAL COLUMBIA PLATEAU

DATE JAN. 1981	DRN. N.K.	SCALE NONE	FIG. 10



R27 E
R 28 E
46°00'
T6N
T5N
T4N
45'
COLUMBIA HILLS ANTICLINE
FOURMILE CANYON
SILLUSI BUTTE
McNary Dam
Substation
McNary
Power City
THE DALLES-UMA
Plymouth
BENTON CO
Umatilla
Irrigon
11
450
UMATILLA B
32
COYOTE COULEE
500
HERMISTON BUTTE
Hermiston
UMATILLA ORDNANCE DEPOT
Water tower
Umatilla Army Depot
595
16
Westland
Ordnance
207
Hinkle
EMIGRANT BUTTES
MAPPING
RROW COUNTY
TILLA COUNTY
Typo
Tyum
Ql-Qgf
Ty
620


15'
R 29 E
R 30 E
46°00'
T6N
T5N
T4N
45'
Ql/Ty
Ql-Qgf
Ty
USI BUTTE
Typo
McNary Dam
UMATILLA CO
McNary
HAT ROCK
STATE PARK
DALLES-UMATILLA SYNCLINE
UMATILLA BUTTE
Tyum
RUSH CANYON
WASHINGTON
BURLINGTON
NORTHERN
UNION PACIFIC
784
COLD
SPRINGS
COLD SPRINGS
NWR
Hermiston State
637
620
FOURMILE GAP
DESPAIN GULCH
900
STAGE GULCH
1100
Stanfield
UTTES
910
MAPPING
Echo
900
1228



GEOLOGIC UNITS

Qd

Sand Dunes (Holocene)

Active and stabilized eolian dunes of basaltic and quartzit
to fine-grained sand: includes Qd (dune sand) of Rockwell
(active sand dunes) and Qds (stabilized sand dunes) of Rigb
berg (1979).

Ql

Loess (Holocene)

Eolian silt and fine sand with volcanic ash units and petro
horizons derived largely from erosion of Qgf and Qt: inclu
(loess), Qp (Palouse Formation) of Newcomb (1965); Ql (loes
of Rigby and Othberg (1979); and Qts (Palouse Formation) of
(1979).

Qa

Alluvium (Holocene)

Fluvial sand, silt and gravel of variable thickness deposit
in floodplains, valley bottoms, and fans: includes Qua (yo
Qoa (older alluvium), Quv (deposits of upper valley terrace
(1965); Qaf (alluvial fan deposits) and Qafo (older alluvia
of Rigby and Othberg (1979).

Qgf Qt

Glaciofluviatile Deposits and Touchet Beds (Pleist

Qgf - Sand and gravel deposits of high energy environments
Pleistocene floods: includes Qu (glaciofluviatile deposits
tiated) of Newcomb (1965); Qhp (Pasco Gravels) of Rockwell
Qfg (catastrophic flood gravels) of Rigby and Othberg (1979
Qt - Silt and sand with stringers of sand and gravel deposi
energy environments of Pleistocene floods (Touchet Beds of
includes Qt (Touchet Beds) of Newcomb (1965); and Qht (Touc
Rigby and Othberg (1979).

Note: Qt undifferentiated from Qgf in Plate 1 (Pendleton q

Qts

Plio-Pleistocene Sedimentary Rocks

Cobbles, gravel, and boulders of basalt with silt and sand
cludes Qcq (old gravel and clay), Qr (Ringold Formation) of
(1965); Trs, Trc, Trf (Ringold Formation) of Rockwell (1979

4

ne)

c and quartzitic, medium-
) of Rockwell (1979); Qda
dunes) of Rigby and Oth-

nits and petrocalcic
and Qt: includes Qlu
965); Ql (loess)
Formation) of Rockwell

e)

ckness deposited by streams
cludes Qua (young alluvium),
valley terraces) of Newcomb
(older alluvial fan deposits)

t Beds (Pleistocene)

environments of catastrophic
atile deposits, undifferen-
.) of Rockwell (1979); and
Othberg (1979).
gravel deposited in low
uchet Beds of Flint, 1938):
; and Qht (Touchet Beds) of

l (Pendleton quadrangle).

itary Rocks

silt and sand matrix: in-
l Formation) of Newcomb
Rockwell (1979); and Tr

LEGEND

GEOLOGIC CONTACTS

$\frac{Ql}{Ty}$ Unit of upper symbol mantles unit of lower symbol

$\frac{Ql-Qgf}{Ty}$ Undifferentiated units mantle lower units

FAULTS: Solid where exposed, dashed where inferred, dotted where covered, queried where questionable.

U D U and D denote sense of apparent vertical offset.

Major fault or fault zone

Strike slip; parallel arrows indicates sense of slip

Apparent strike slip; double ended arrow indicates sense unknown.

Apparent dip slip; ball on downthrown side.

85 8 Barb indicates direction of dip and degree of dip where known. Arrow indicates rake of striae and degrees of rake.

Thrust fault; sawteeth on upper plate

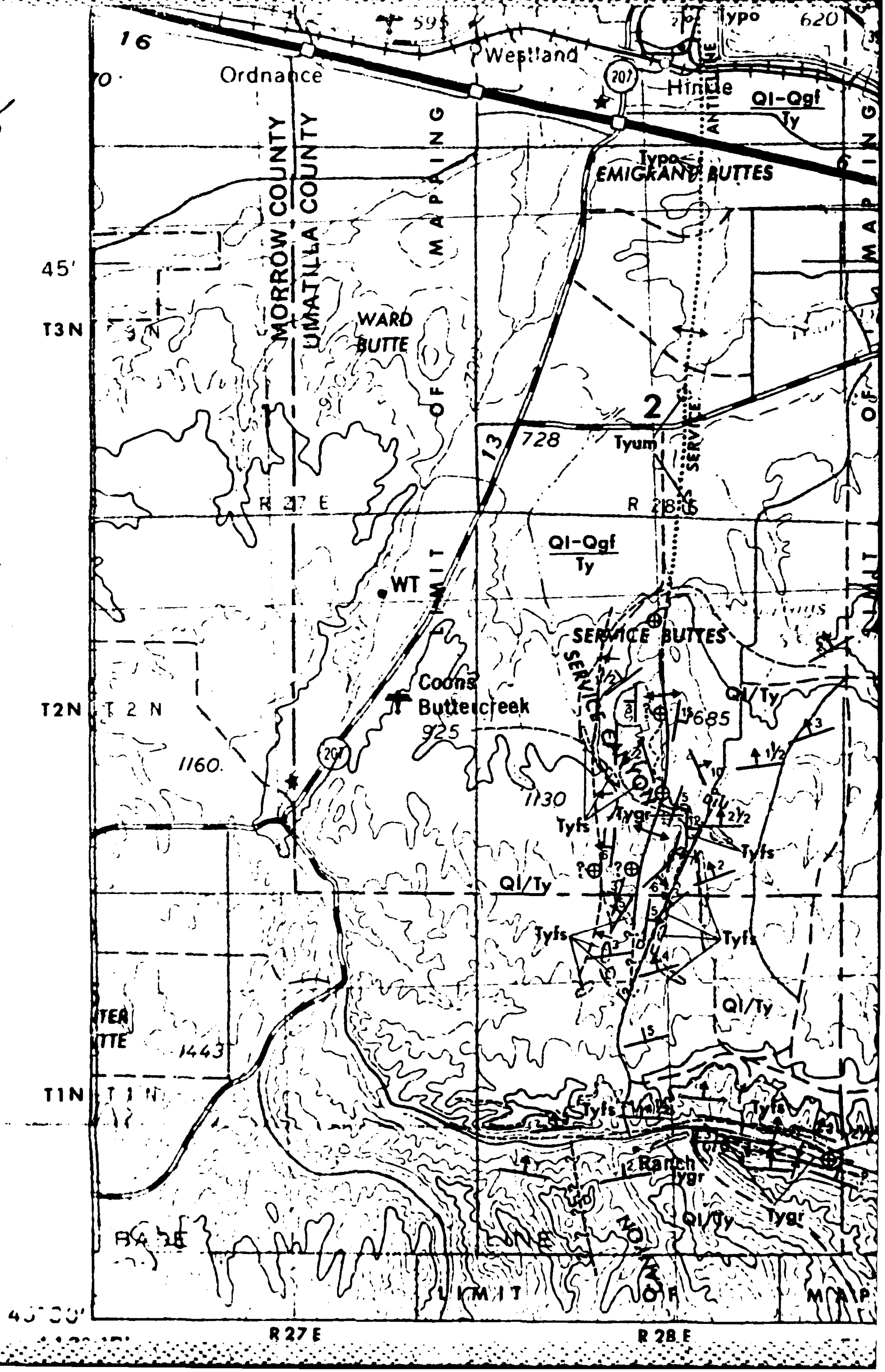
FOLDS: Solid where exposed, dashed where inferred, dotted where covered, queried where questionable. Arrow shows direction of plunge if any.

Anticline

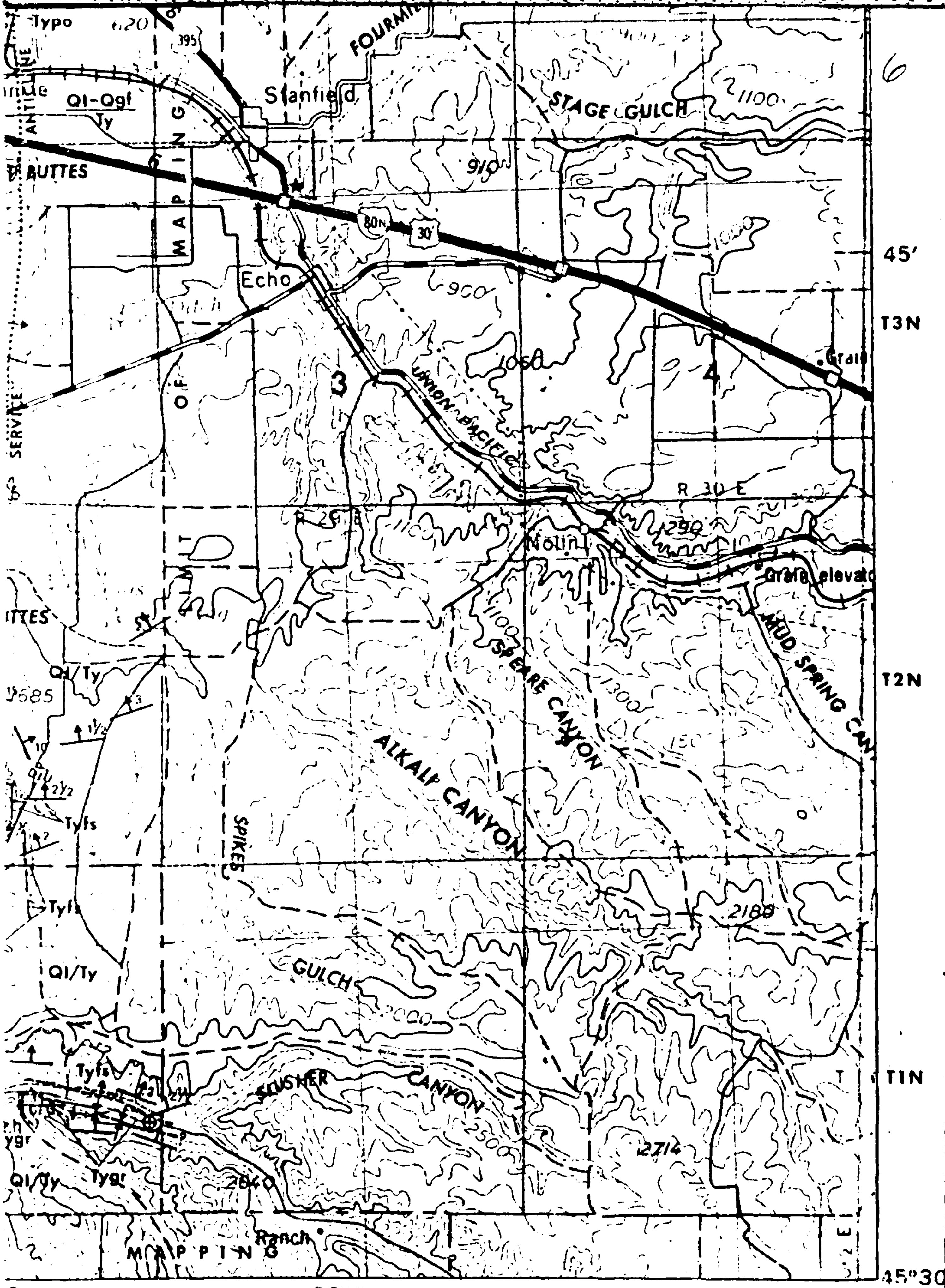
Syncline

Monocline; arrow points in direction

5



16
Ordnance
Westland
Hinkle
Typo
620
595
207
Ql-Qgf
Ty
EMIGRANT BUTTES
ANTICLINE
MORROW COUNTY
UMATILLA COUNTY
LIMIT OF MAPPING
45'
T3N
WARD BUTTE
2
728
13
Tyum
SERVICE
R 27 E
R 28 E
Ql-Qgf
Ty
WT
SERVICE BUTTES
Coons
Buttercreek
925
T2N
T 2 N
1160
685
1130
Tygr
Tyfs
Ql/Ty
1443
T1N
T 1 N
Ranch
Tygr
Ql/Ty
LIMIT OF MAP
R 27 E
R 28 E



6
Typo
620
395
FOURMILE
Stanfield
STAGE GULCH
1100
Ql-Qgf
Ty
ANTICLINE
BUTTES
910
80N
30
MAPPING
Echo
900
45'
T3N
1050
3
4
Grain
UNION PACIFIC
SERVICE
OF
R 30 E
R 29 E
1100
Nolin
1290
Grain elevator
LIMIT
BUTTES
1100
SPEARE CANYON
MUD SPRING CANYON
Ql/Ty
1300
T2N
1585
ALKALI CANYON
Tyfs
SPIKES
Tyfs
2180
GULCH
Ql/Ty
2000
Tyfs
SLUSHER
CANYON
T1N
2500
2714
Tygr
Ql/Ty
Tygr
2640
Ranch
MAPPING
45°30

7

45'

T3N

T2N

T1N

45°30'

Qfg (catastrophic flood gravels) of Rigby and Othberg (1979).
Qt - Silt and sand with stringers of sand and gravel deposited in low energy environments of Pleistocene floods (Touchet Beds of Flint, 193 includes Qt (Touchet Beds) of Newcomb (1965); and Qht (Touchet Beds) Rigby and Othberg (1979).

Note: Qt undifferentiated from Qgf in Plate 1 (Pendleton quadrangle)

Qts

Plio-Pleistocene Sedimentary Rocks

Cobbles, gravel, and boulders of basalt with silt and sand matrix: includes Qcq (old gravel and clay), Qr (Ringold Formation) of Newcomb (1965); Trs, Trc, Trf (Ringold Formation) of Rockwell (1979); and Tr (Ringold Formation) of Rigby and Othberg (1979). Also locally includ waterlain tuffs and tuffaceous sandstones; equivalent to the Dalles Formation, post-basalt sediments of Ellensburg Formation and Ringold Formation.

Ty

Columbia River Basalt Group
Yakima Basalt Subgroup (Miocene)

Tholeiitic basalt flows of the Saddle Mountains, Wanapum and Grande Ronde Formations. Locally includes talus, colluvium and thin loess deposits which overlie the basalt flows. Individual members are identified as follows:

Tysm - Saddle Mountain Basalt Formation (undifferentiated)
- Tylm - Lower Monumental Member
- Tyih - Ice Harbor Member
- Tyem - Elephant Mountain Member
- Typo - Pomona Member (includes Esquatzel member)
- Tyum - Umatilla Member (includes Wilbur Cr. member)

Tyw - Wanapum Basalt Formation (undifferentiated)
- Typr - Priest Rapids Member
- Tyro - Roza Member
- Tyfs - Frenchman Springs
  - Tydo - Dodge flow of Eckler Mountain Member

Tygr - Grande Ronde Basalt Formation, (undifferentiated) Includes fl of N1, N2, R1 and R2 magnetic polarities.

pT

Pre-Tertiary

Pre-Tertiary rocks, undifferentiated (Precambrian through Mesozoic) metamorphic and plutonic rocks which are locally exposed below the Columbia River Basalt flows: includes TpCr (rocks older than basalt of the Columbia River Group) of Newcomb (1970); TMzg, (plutonic rock MzPzm (metamorphic rocks) Rockwell (1979); and pm (pre-Miocene rocks undifferentiated) of Rigby and Othberg (1979).

NOTES

GEOLOGIC CONTACTS MODIFIED FROM GARD AND WALDRON (1954), TRIMBLE (1954), WALDRON AND GARD (1954 & 1955), NEWCOMB (1965 1970), MOLENAAR (1968), KIENLE AND NEWCOMB (1973), SWANSON OTHERS (1977 & 1979), KIENLE AND OTHERS (1979), RIGBY AND

ɪrg (1979).
ɪl deposited in low
Beds of Flint, 1938):
ɪht (Touchet Beds) of

ɪdleton quadrangle). 8

ɪocks

ɪnd sand matrix in-
ɪtion) of Newcomb
ɪll (1979); and Tr
ɪlso locally includes
ɪnt to the Dalles
ɪation and Ringold

up
ene)

ɪanapum and Grande
um and thin loess
ɪal members are

ntiated)

ɪmber)
member)

ɪber
ɪiated) Includes flow

through Mesozoic)
ɪxposed below the
older than basalt
ɪzg, (plutonic rocks),
(pre-Miocene rocks,

ɪRON (1954),
ɪ), NEWCOMB (1965
(1973), SWANSON
1979), RIGBY AND

Thrust fault;
plate

FOLDS: Solid where exposed, dashed where inferred, dotted where covered, queried where questionable. Arrow shows direction of plunge if any.

Anticline

Syncline

Monocline; arrow points in direction of decreasing dip

Monocline; arrow points in direction of increasing dip

Ty Dike

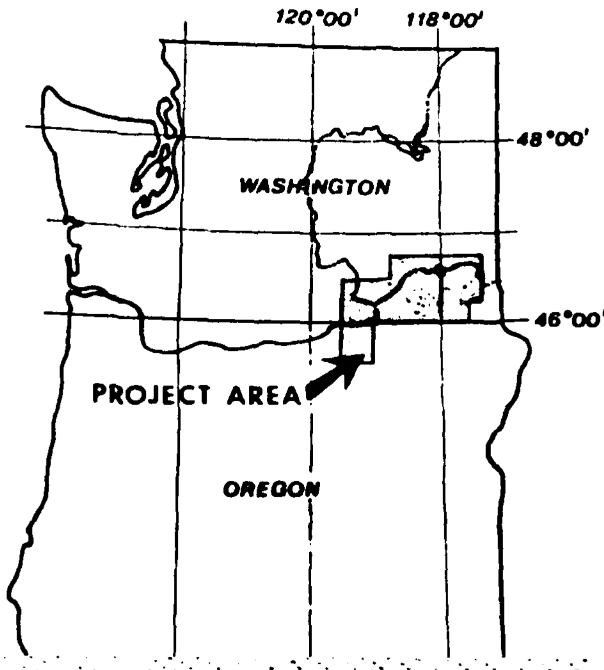
Horizontal bedding

10 Measured strike and dip

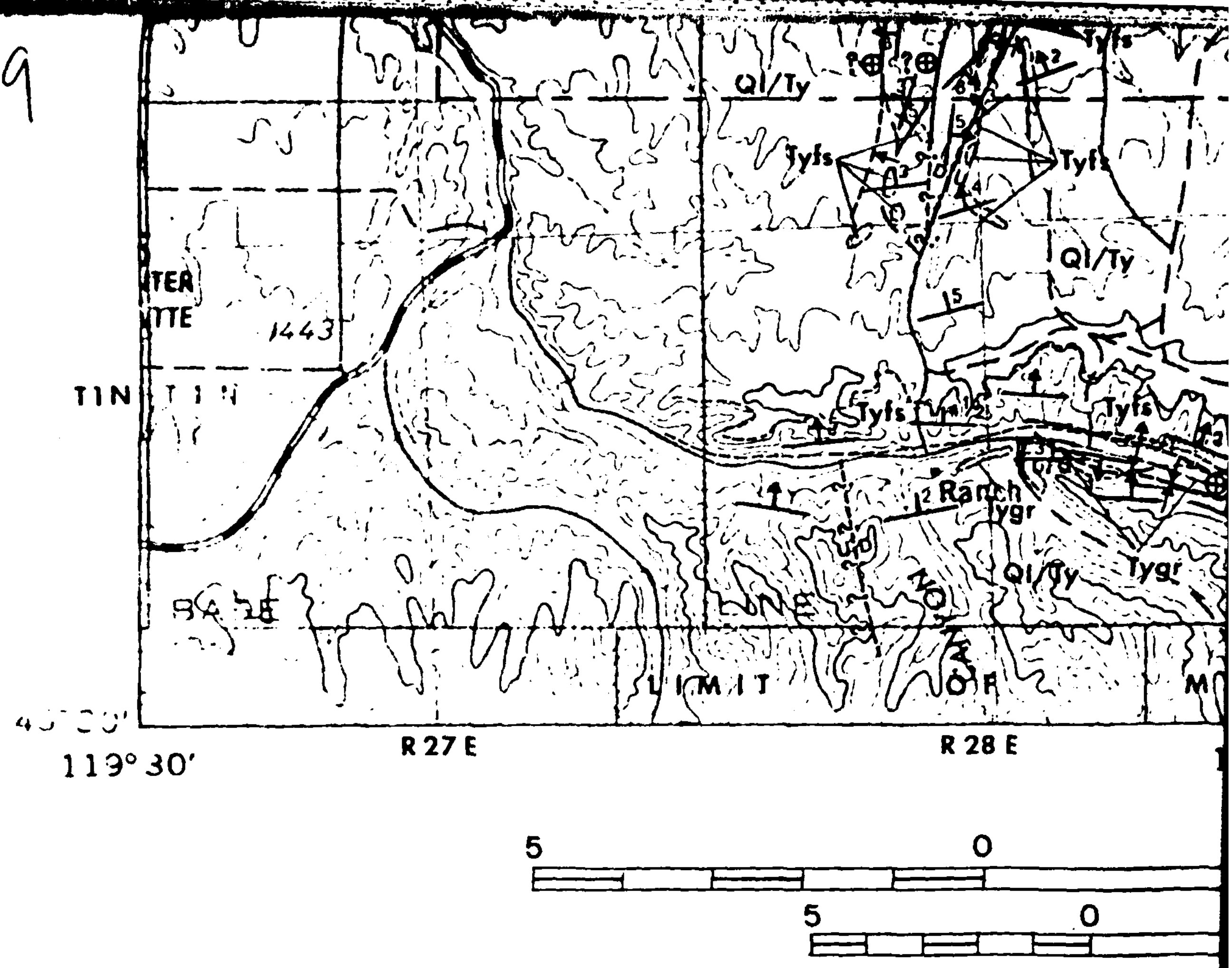
3 Apparent strike and dip

A A' Geologic cross-section

VICINITY MAP



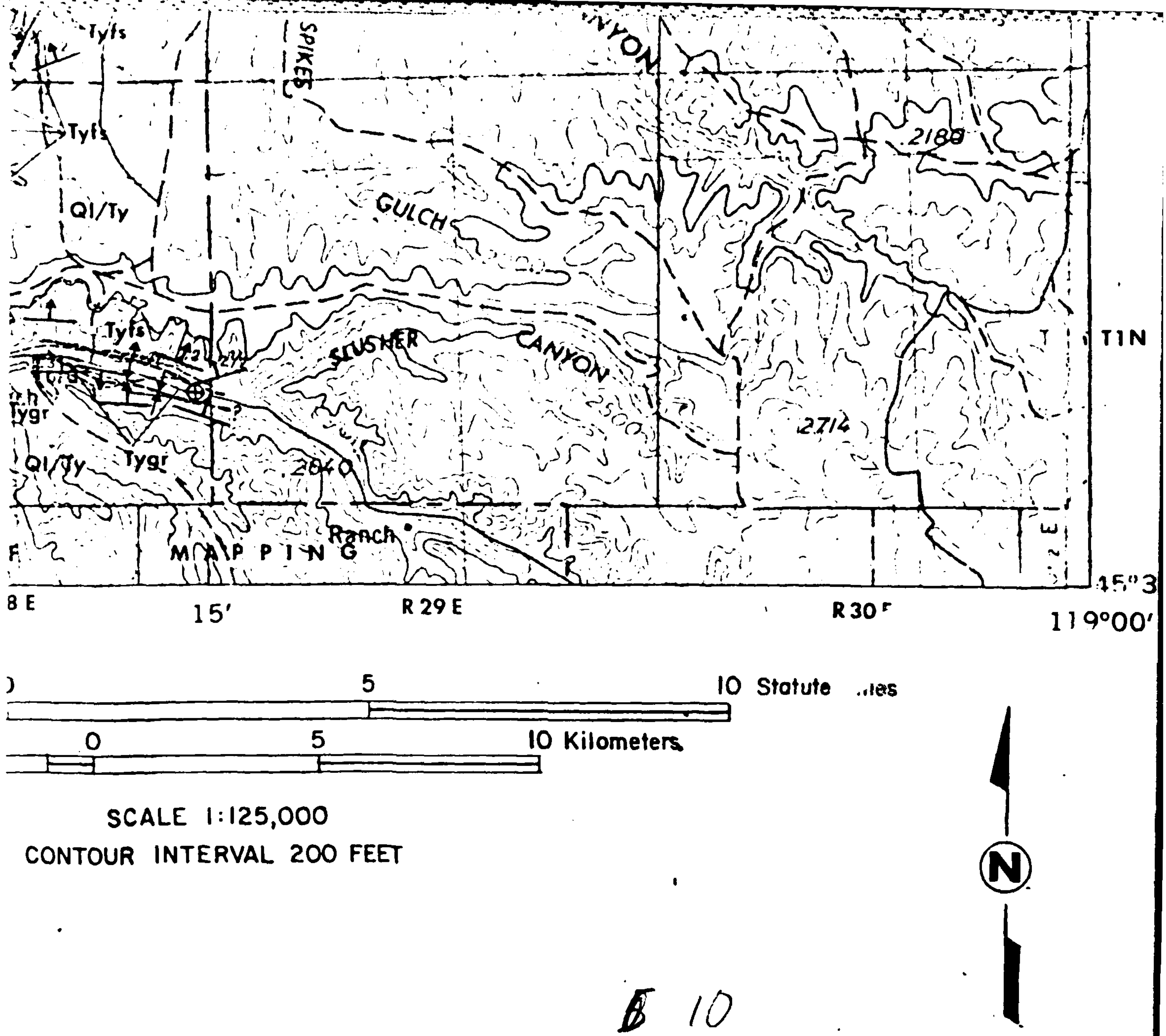
9



SCALE

CONTOUR INT

41


Tyfs
SPIKES
GULCH
2180
Ql/Ty
T1N
SLUSHER
CANYON
Tyfs
Tygr
2500
2714
Ql/Ty
Tygr
2040
Ranch
M A P P I N G
R 29 E
15′
R 30
119°00′
5
10 Statute
5
10 Kilometers
SCALE 1:125,000
CONTOUR INTERVAL 200 FEET
N

10

NOTES

GEOLOGIC CONTACTS MODIFIED FROM GARD AND WALDRON (1954
TRIMBLE (1954), WALDRON AND GARD (1954 & 1955), NEWCOM
& 1970), MOLENAAR (1968), KIENLE AND NEWCOMB (1973), S
AND OTHERS (1977 & 1979), KIENLE AND OTHERS (1979), RI
OTHBERG (1979) AND ROCKWELL (1979).

GEOLOGIC AND TECTONIC RECONNAISSANCE BY C.F. KIENLE, J
HAMILL, K.E. LITE AND G.L. PETERSON.

BASE MAP FROM U.S. CORPS OF ENGINEERS, ARMY MAP SERVIC
1:250,000 SCALE.

11

fferentiated) Includes flow
arities.

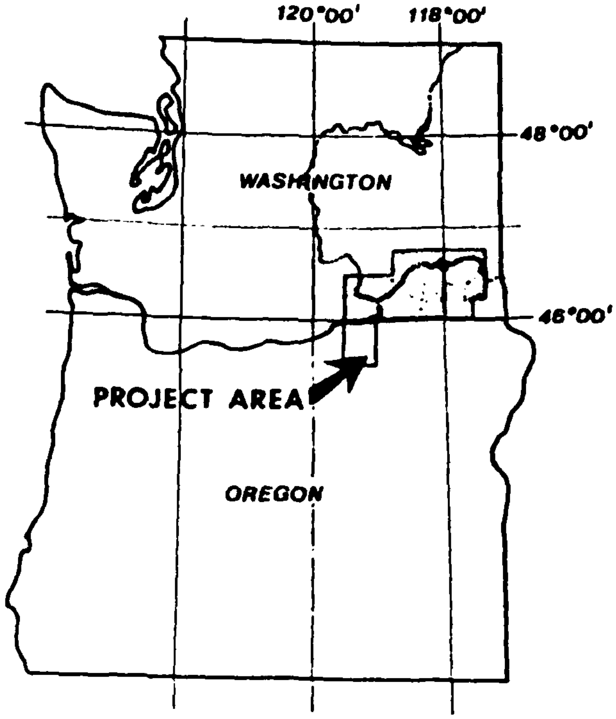
mbrian through Mesozoic)
cally exposed below the
(rocks older than basalt
970); TMzg, (plutonic rocks),
and pm (pre-Miocene rocks,
79).

ND WALDRON (1954),
& 1955), NEWCOMB (1965
EWCOMB (1973), SWANSON
THERS (1979), RIGBY AND

Y C.F. KIENLE, JR., M.L.

, ARMY MAP SERVICE,

VICINITY MAP



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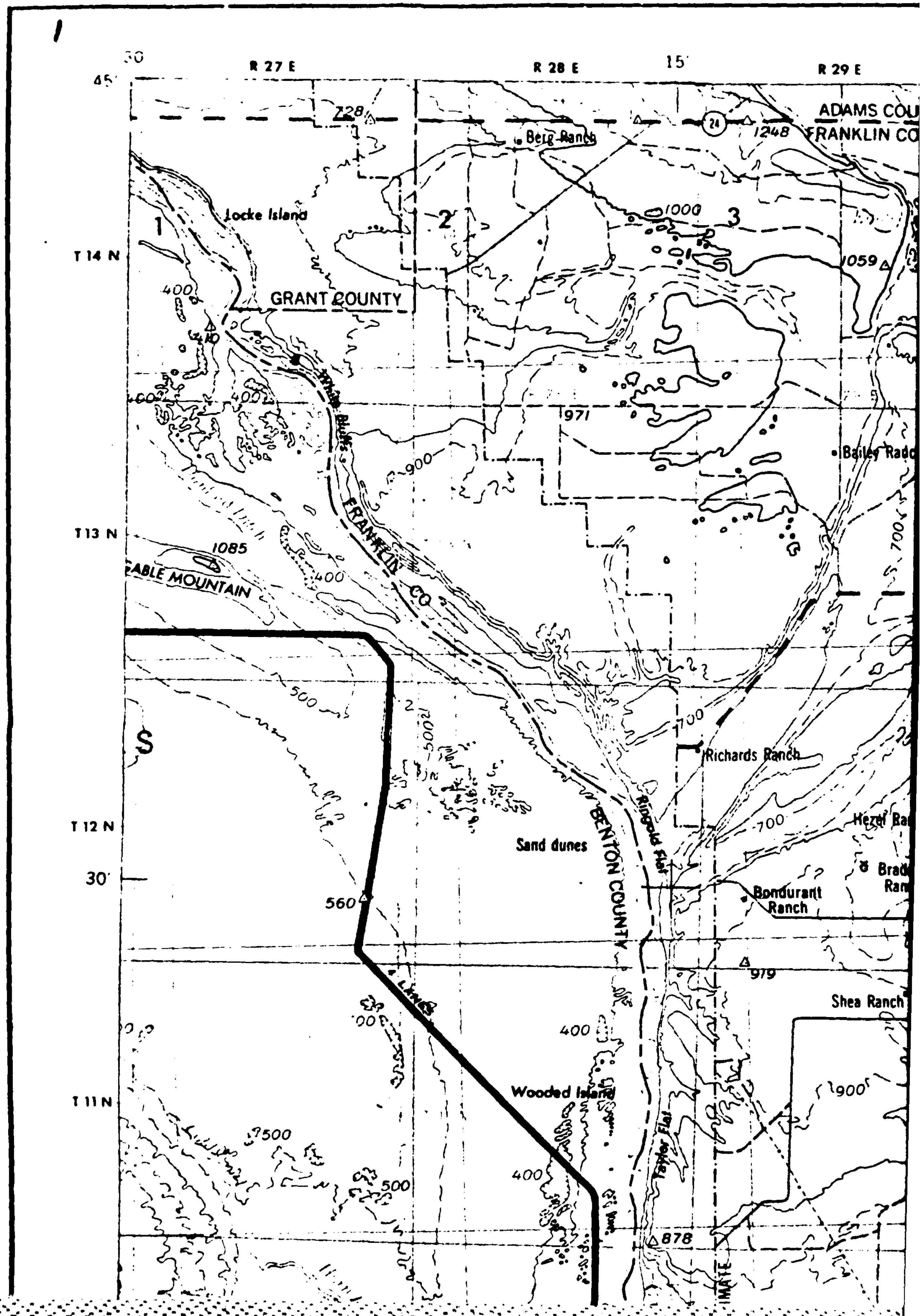
PORTLAND, OREGON

U.S. CORPS OF ENGINEERS
DACW67-80-C-0125

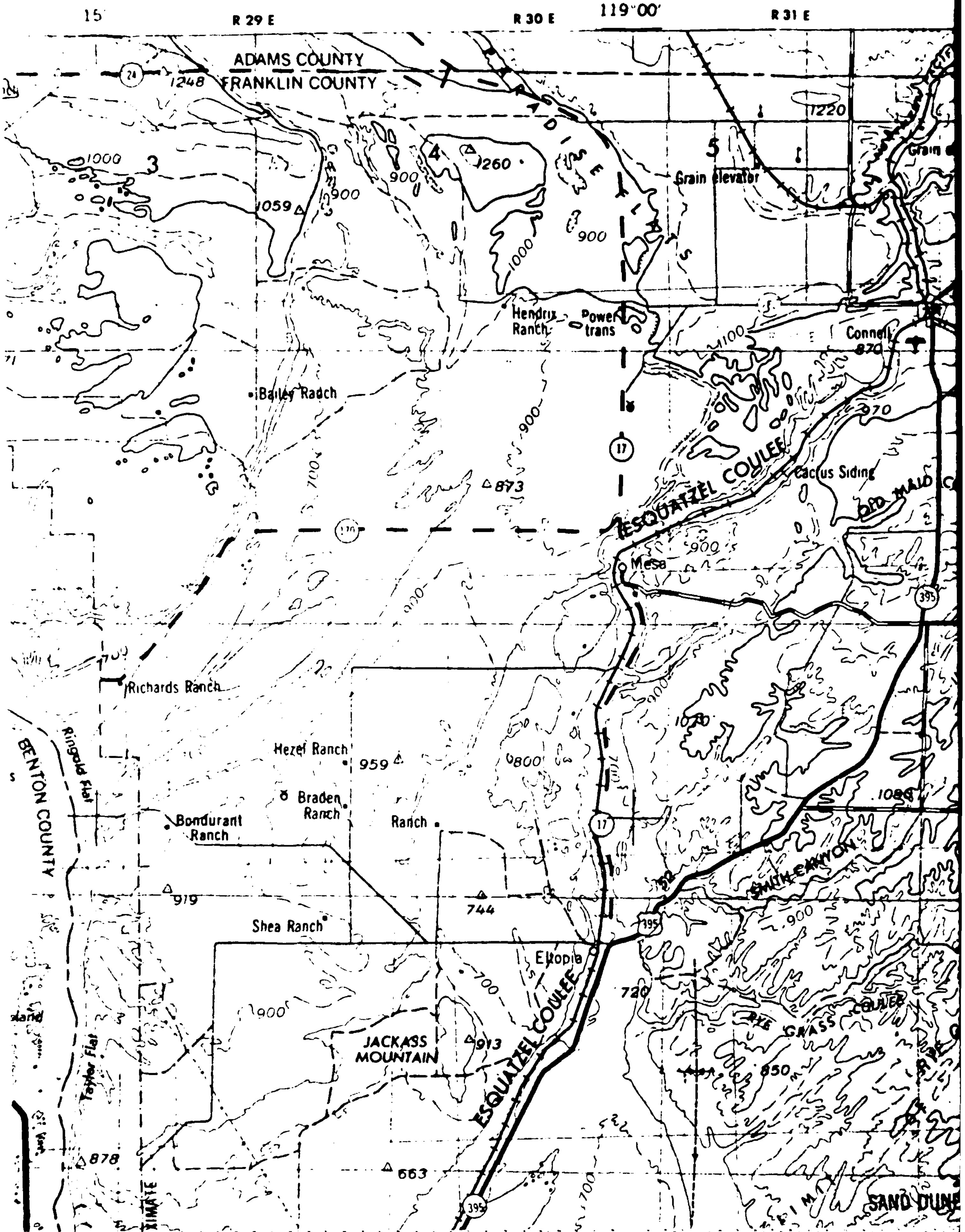
RECONNAISSANCE GEOLOGIC AND TECTONIC MAP
OF THE SERVICE ANTICLINE, OREGON AND WASHINGTON

SCALE 1:125,000	DRN M. KELLY	NO. PLATE I
DATE NOV. 1980	CHK/APP C.F. KIENLE	SHEET



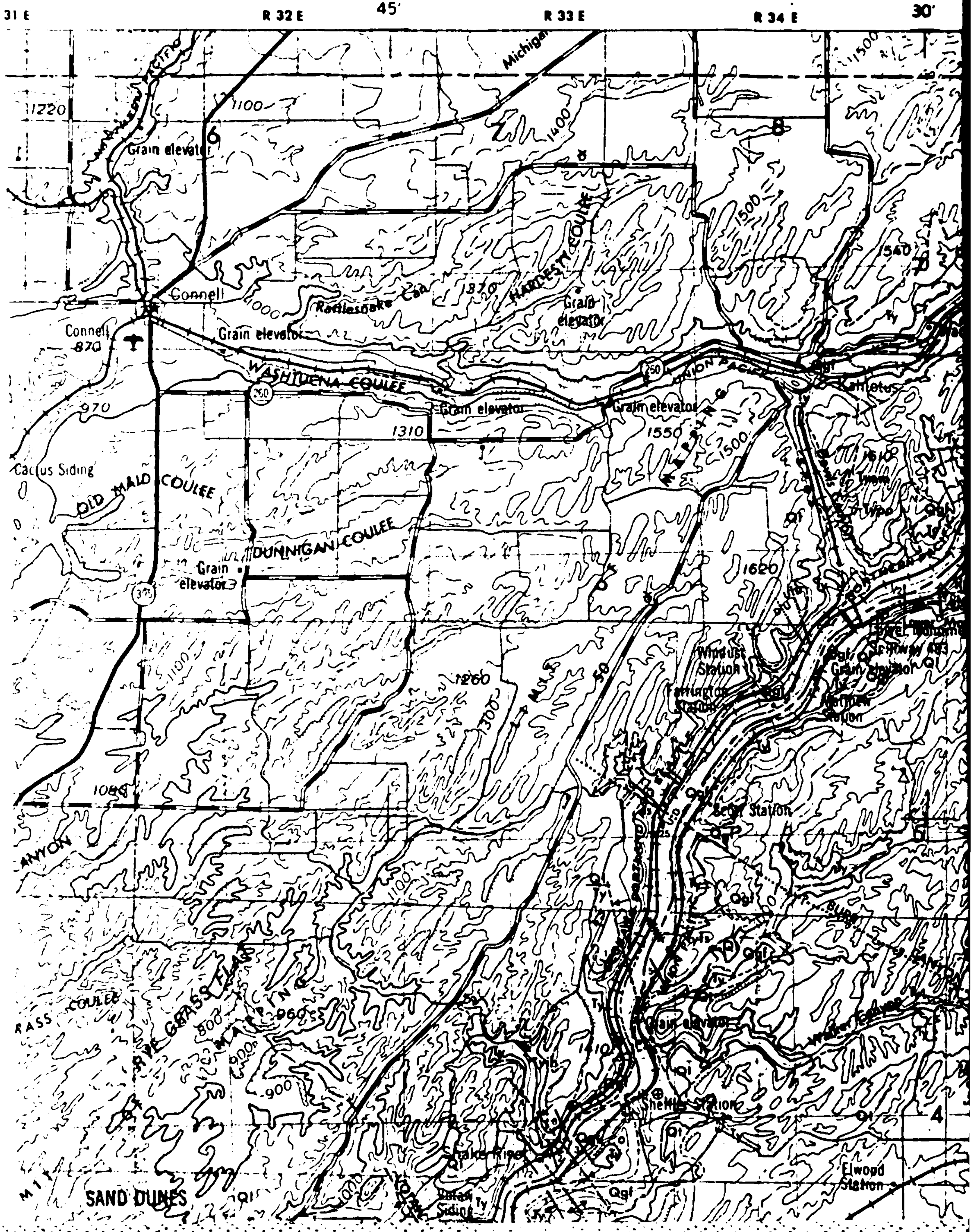
1
R 27 E
R 28 E
R 29 E
15'
45'
T 14 N
T 13 N
T 12 N
T 11 N
30'
ADAMS COU
FRANKLIN CO
Berg Ranch
1248
1000
3
2
1
Locke Island
1059
GRANT COUNTY
400
410
971
Bailey Radd
900
1085
GABLE MOUNTAIN
FRANKLIN CO
700
500
S
Richards Ranch
Ringold Flat
BENTON COUNTY
Sand dunes
Hezel Ra
Bondurant Ranch
560
979
Shea Ranch
400
Wooded Island
900
500
Taylor Flat
878

2



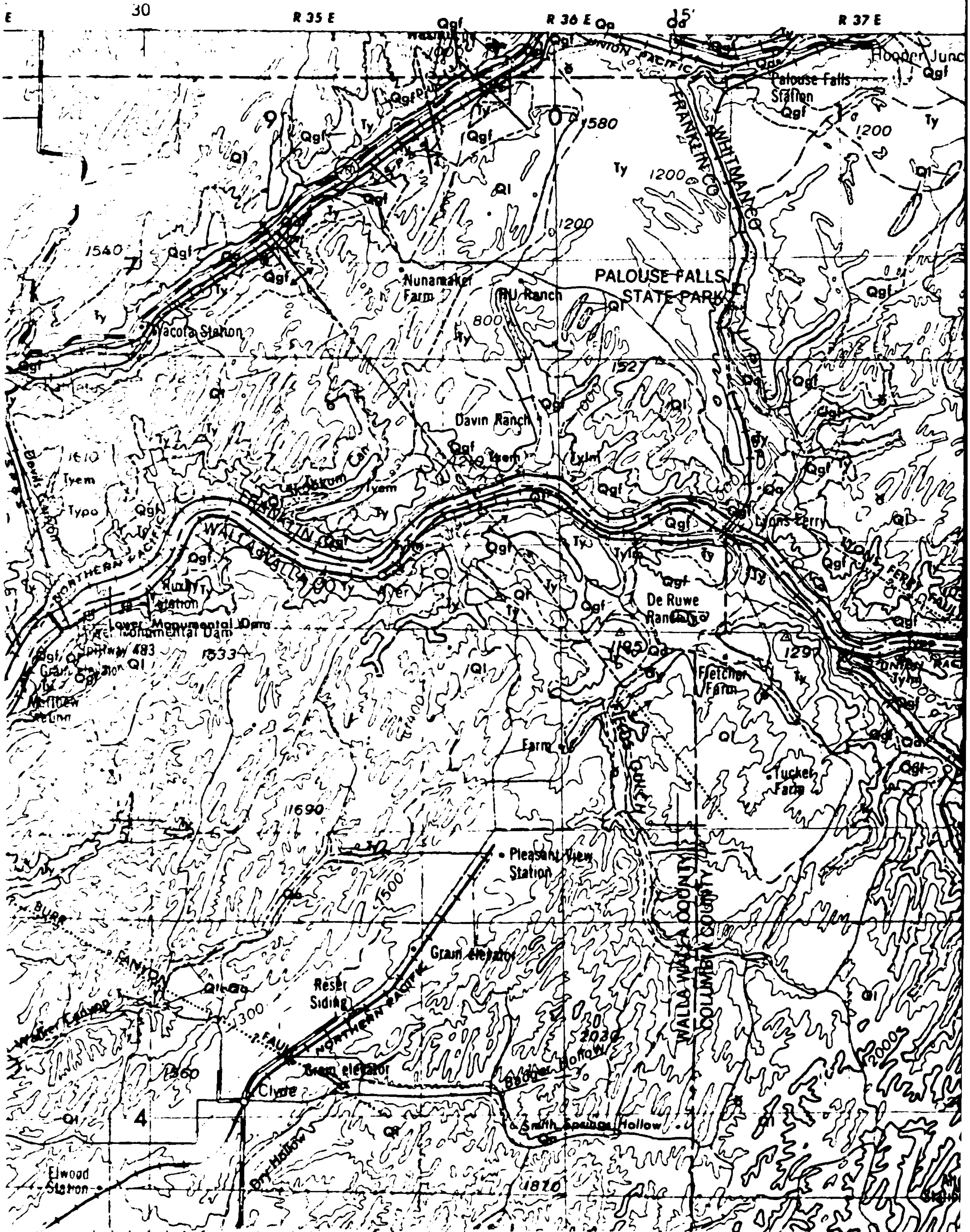
15'
R 29 E
R 30 E
119°00'
R 31 E
ADAMS COUNTY
FRANKLIN COUNTY
1248
1220
1000
3
4
1260
5
Grain Elevator
900
1059
Hendrix Ranch
Power trans
Connell
870
Bailey Ranch
17
ESQUATZEL COULEE
Cactus Siding
873
Mesa
395
Richards Ranch
Hezel Ranch
959
800
Braden Ranch
Ranch
Bondurant Ranch
BENTON COUNTY
Ringold Flat
919
744
Shea Ranch
Eltopia
720
SMITH CANYON
RYE GRASS COULEE
JACKASS MOUNTAIN
913
850
Taylor Flat
878
663
700

3

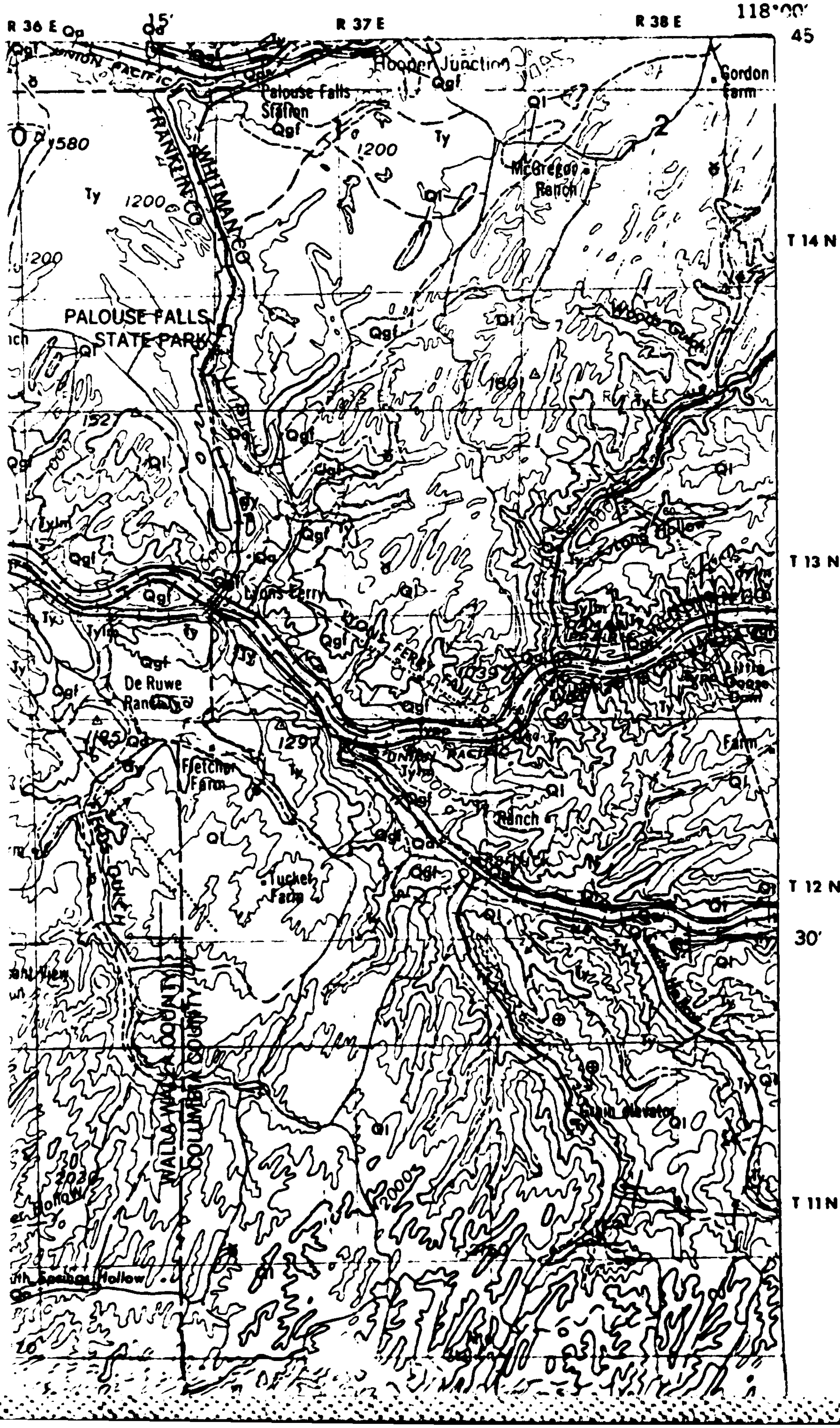


31 E
R 32 E
45'
R 33 E
R 34 E
30'
1220
1100
Michigan
1400
1500
Grain elevator
6
8
Connell
Connell
870
Rattlesnake Can
1870
HARDESTY COULEE
Grain elevator
Grain elevator
WASHTUCNA COULEE
260
UNION PACIFIC
Kahlotus
970
Grain elevator
Grain elevator
1310
1550
1500
1560
1610
Cactus Siding
OLD MAID COULEE
DUNNIGAN COULEE
Grain elevator
395
1620
1100
1260
1300
Windust Station
Farrington Station
Grain elevator
Matthew Station
1080
CANYON
Sedor Station
1100
COULEE
RASS
RYE GRASS FLAT
800
960
900
900
Grain elevator
1410
Shelling Station
Snake River
4
Elwood Station
SAND DUNES
Siding
Qgl
Qt
Ty

4


R 35 E
R 36 E
R 37 E
UNION PACIFIC
Palouse Falls Station
Hooper Junc
FRANKLIN CO
WHITMAN CO
PALOUSE FALLS STATE PARK
Nunamaker Farm
Ayacota Station
Davin Ranch
NORTHERN PACIFIC
WALLA WALLA CO
Lyons Ferry
Lower Monumental Dam
De Ruwe Ranch
Fletcher Farm
Tucker Farm
Farm
Pleasant View Station
Grain elevator
Reser Siding
WALLA WALLA COUNTY
COLUMBIA COUNTY
Clyde
Smith Springs Hollow
Dry Hollow
Elwood Station
Walker Canyon
Devils Canyon

5



Active and sta
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Eolian silt an
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of Rigby and Ot
(1979).

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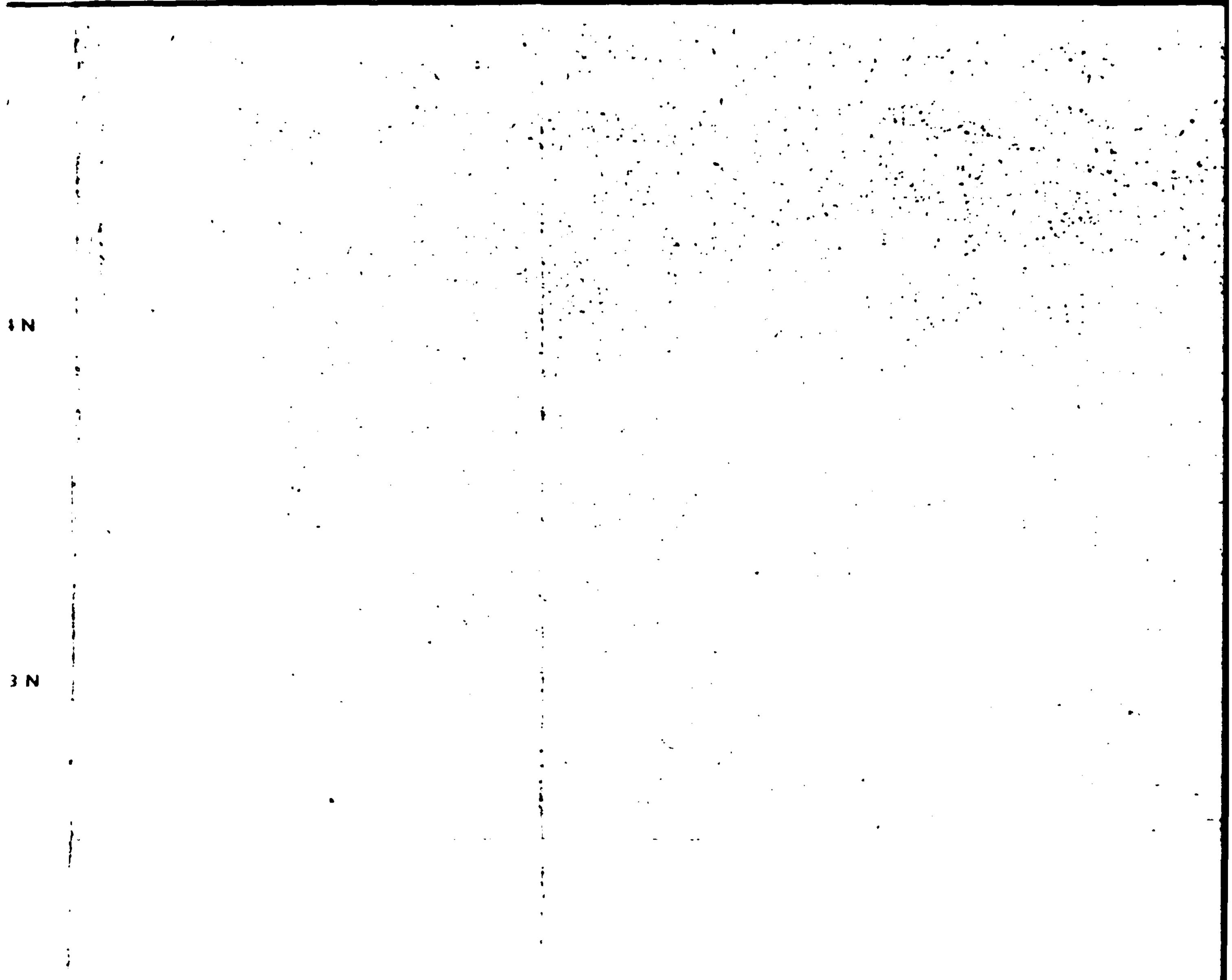

GEOLOGIC UNITS

Qd

Sand Dunes (Holocene)

Active and stabilized eolian dunes of basaltic and quartzitic, medium- to fine-grained sand: includes Qd (dune sand) of Rockwell (1979); Qda (active sand dunes) and Qds (stabilized sand dunes) of Rigby and Othberg (1979).

Ql

Loess (Holocene)

Eolian silt and fine sand with volcanic ash units and petrocalcic horizons derived largely from erosion of Qgf and Qt: includes Qlu (loess), Qp (Palouse Formation) of Newcomb (1965); Ql (loess) of Rigby and Othberg (1979); and Qts (Palouse Formation) of Rockwell (1979).

Qa

Alluvium (Holocene)

LEGEN

GEOLOGIC CONTACTS

$\frac{Ql}{Ty}$ Unit of uppe of lower sym

$\frac{Ql-Qgf}{Ty}$ Undifferenti lower units

FAULTS: Solid where ex inferred, dotted where where questionable.

U D U and D deno vertical off

Major fault

Strike slip; dicates sens

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: and quartzitic, medium-
) of Rockwell (1979); Qda
dunes) of Rigby and Oth-

nits and petrocalcic
and Qt: includes Qlu
965); Ql (loess)
Formation) of Rockwell

?)

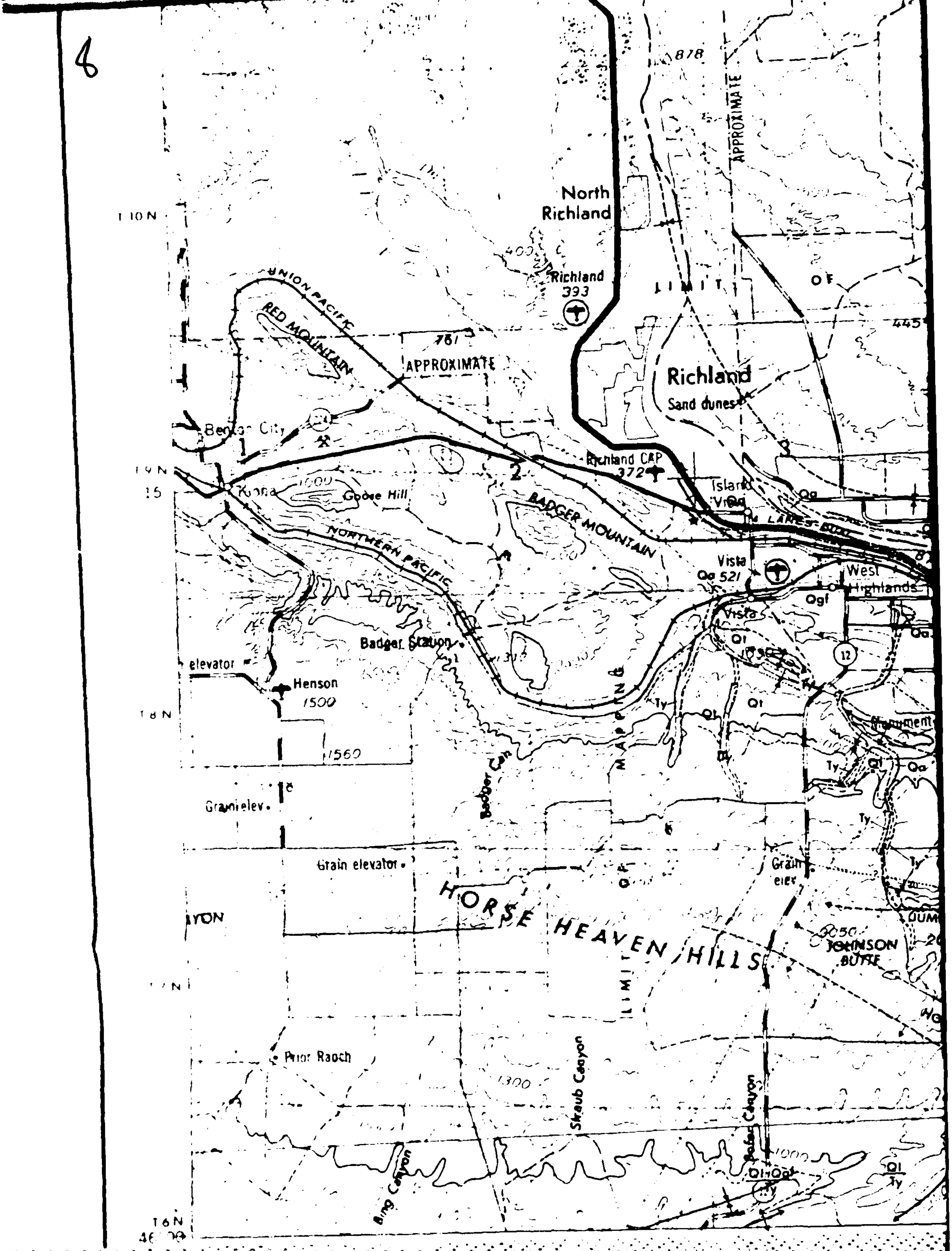
LEGEND

GEOLOGIC CONTACTS

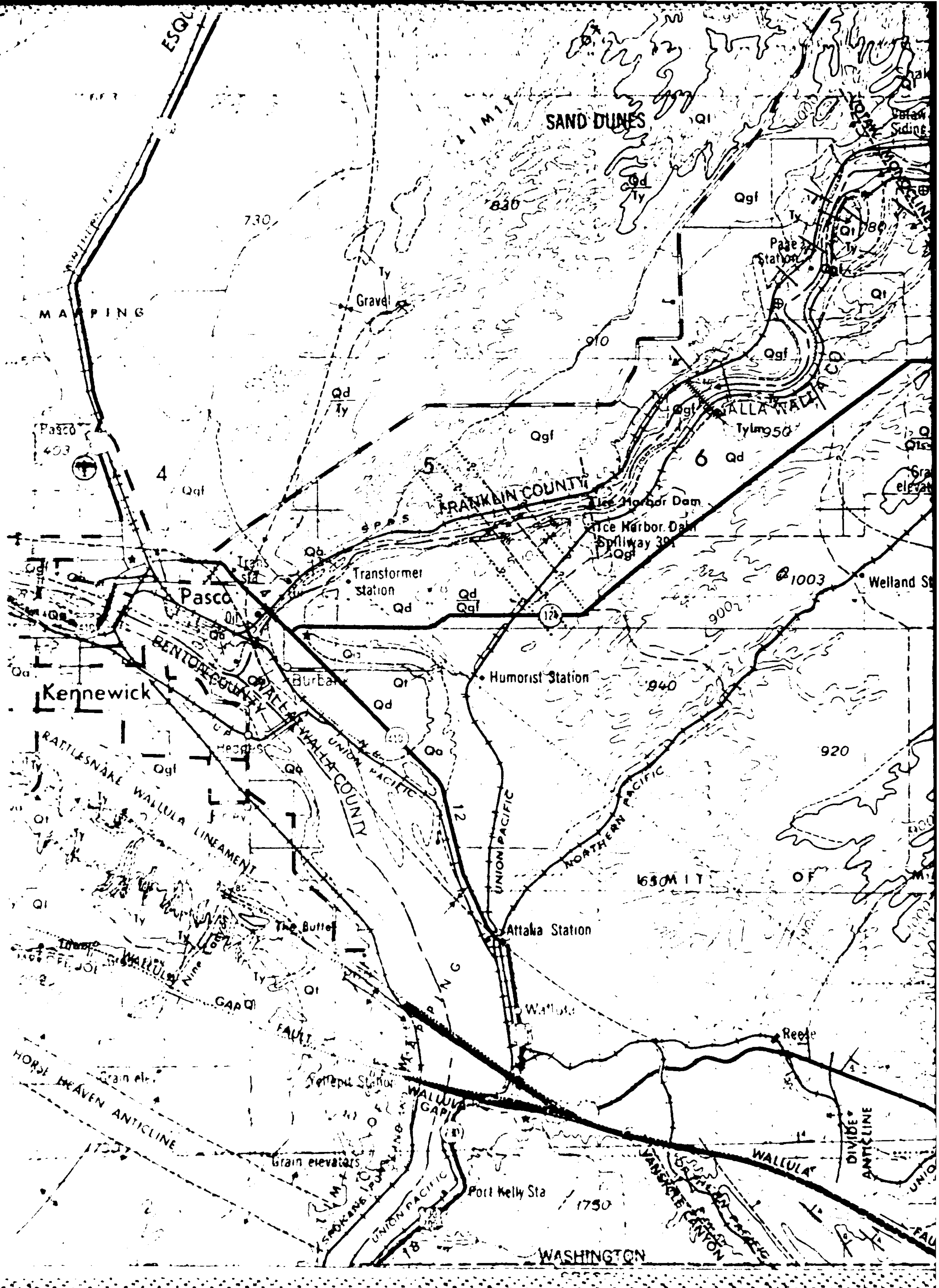
$\frac{Ql}{Ty}$	Unit of upper symbol mantles unit of lower symbol
$\frac{Ql\text{-}Qgf}{Ty}$	Undifferentiated units mantle lower units

FAULTS: Solid where exposed, dashed where inferred, dotted where covered, queried where questionable.

U D	U and D denote sense of apparent vertical offset.
	Major fault or fault zone
	Strike slip; parallel arrows indicates sense of slip


8
878
APPROXIMATE
North
Richland
Richland
393
LIMIT
OF
445
UNION PACIFIC
RED MOUNTAIN
781
APPROXIMATE
Richland
Sand dunes
Benton City
Richland CAP
372
Island
View
Kiona
Goose Hill
BADGER MOUNTAIN
NORTHERN PACIFIC
Vista
521
West
Highlands
Vista
Badger Station
elevator
Henson
1500
1560
MAPPING
Badger Can
Grain elev.
Grain elevator
Grain
elev
HORSE HEAVEN HILLS
JOHNSON
BUTTE
Prior Ranch
1300
Skaub Canyon
Bing Canyon
T10N
T9N
T8N
T6N

9



SAND DUNES
MAPPING
LIMIT OF MAPPING
Pasco
Kennewick
FRANKLIN COUNTY
BENTON COUNTY
WALLA WALLA COUNTY
WALLA WALLA CO
Ice Harbor Dam
Ice Harbor Dam Spillway 391
Transformer Station
Trans Sta
Humorist Station
Attalia Station
Wallula
Reese
Wallula Gap
Port Kelly Sta
Grain elevators
Grain elev
Page Station
Welland St
Gravel
The Butte
RATTLESNAKE WALLULA LINEAMENT
WALLULA FAULT
HORSE HEAVEN ANTICLINE
DIVIDE ANTICLINE
UNION PACIFIC
NORTHERN PACIFIC
SPOKANE PORTLAND
WASHINGTON
Qgf
Qd
Ty
Qt
Qa
Qd/Ty
Qd/Qgf
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830
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950
940
920
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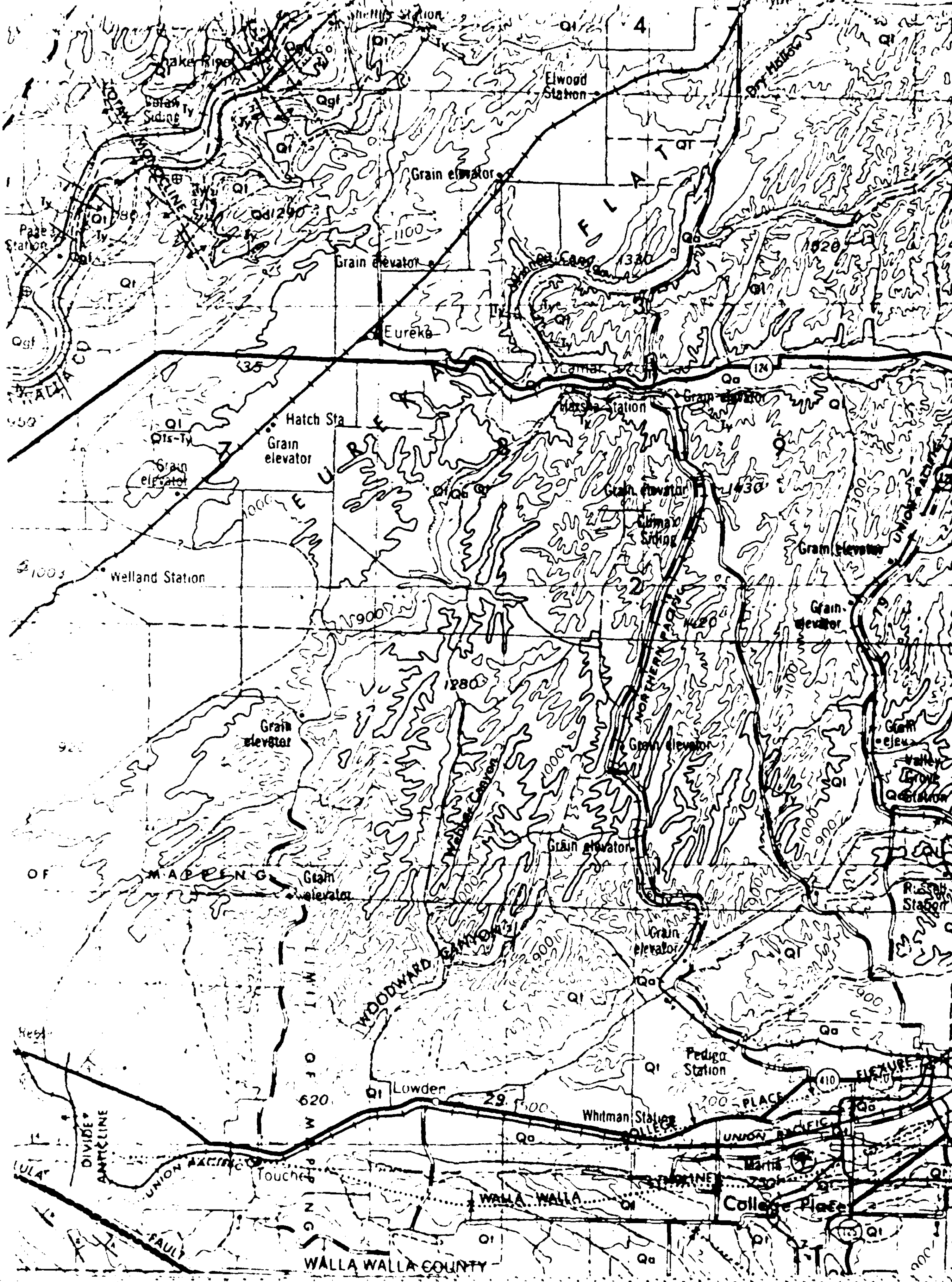
18


Snake River
Elwood Station
Dry Hollow
Grain elevator
Eureka
FLAT
Lamar
Haxsha Station
Hatch Sta
EUREKA
Climax Siding
Welland Station
NORTHERN PACIFIC
UNION PACIFIC
Valley Grove Station
Woodward Canyon
OF MAPPING
LIMIT OF MAPPING
Pedigo Station
Lowder
Whitman Station
COLLEGE PLACE
Touchet
WALLA WALLA
College Place
DIVIDE ANTICLINE
FAULT
WALLA WALLA COUNTY
124
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620

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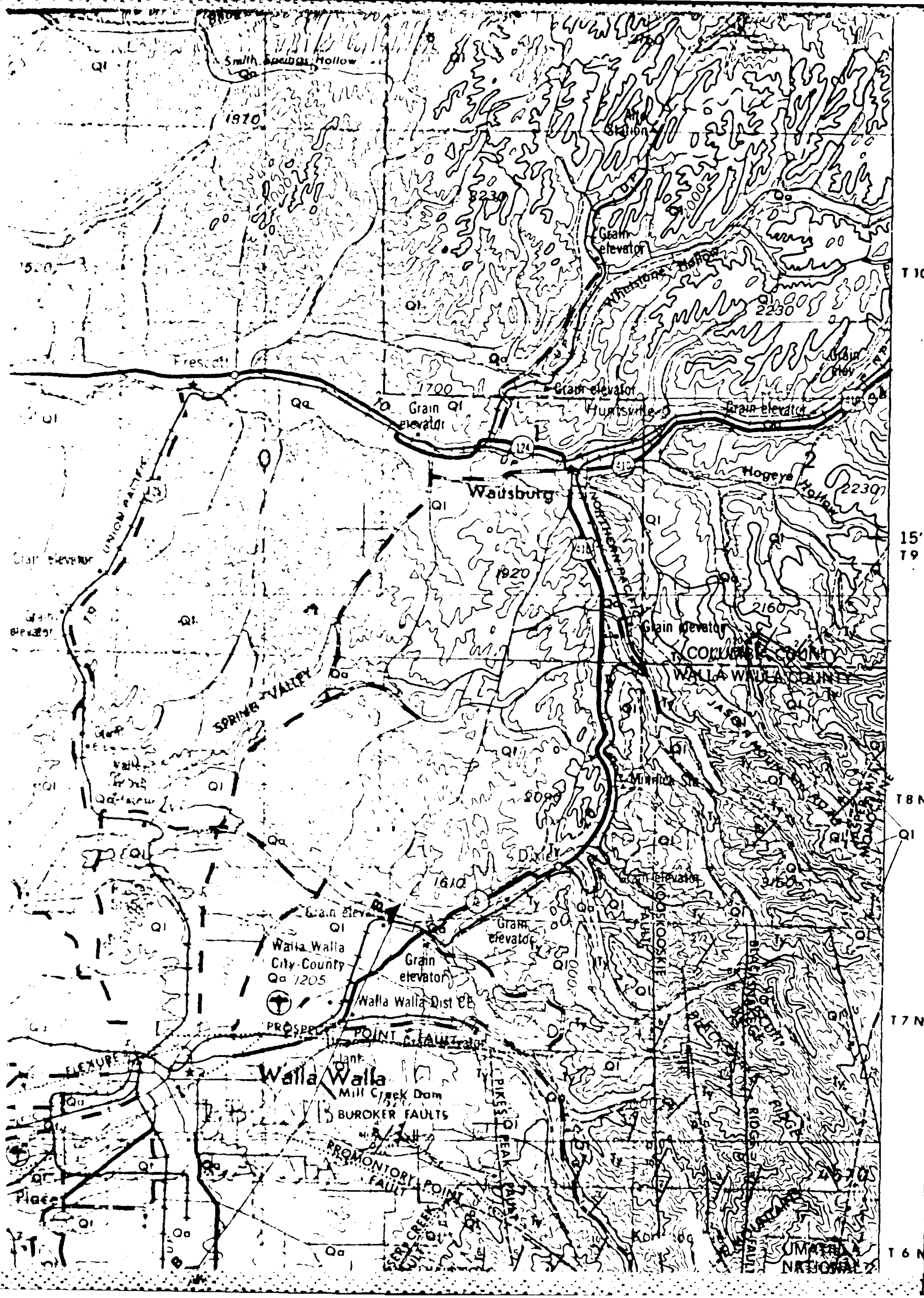

Smith Springs Hollow
Station
Grain elevator
Whetstone Hollow
Prescott
Grain elevator
Huntsville
Waitsburg
Hogeye Hollow
UNION PACIFIC
NORTHERN PACIFIC
SPRING VALLEY
Grain elevator
COLUMBIA COUNTY
WALLA WALLA COUNTY
JASPER MOUNTAIN ROAD
Minnick Sta
Dixie
Walla Walla City-County
Grain elevator
Walla Walla Dist CE
PROSPECT POINT FAULT
FLEXURE
Walla Walla
Mill Creek Dam
BUROKER FAULTS
PROMONTORY POINT FAULT
PIKES PEAK
KOOSKOOSKIE
BLACKSNAKE RIDGE
Kooskooskie
UMATILLA NATIONAL
Q1
Qa
Ty
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2230
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2090
1610
1205
2670
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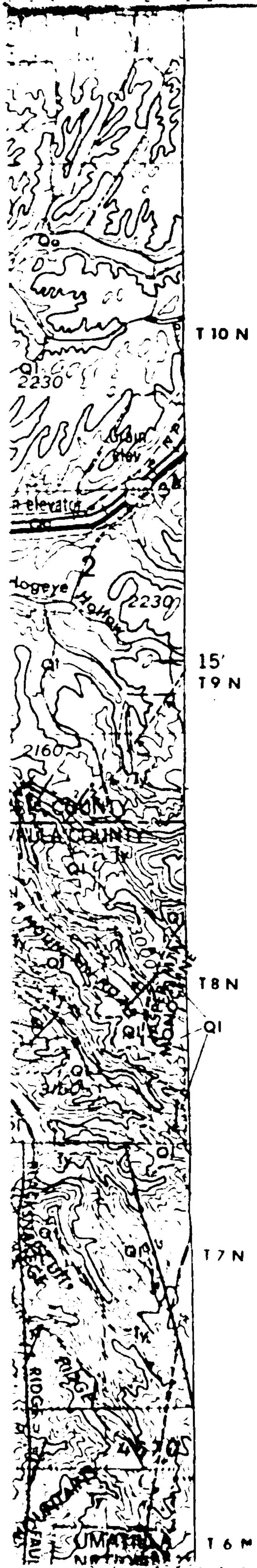
15′
T 9
T 8 N
T 7 N
T 6 N

12



Eolian silt and fine sand with volcanic ash units and petrocalcic horizons derived largely from erosion of Qgf and Qt: includes Qlu (loess), Qp (Palouse Formation) of Newcomb (1965); Ql (loess) of Rigby and Othberg (1979); and Qts (Palouse Formation) of Rockwell (1979).

Qa

Alluvium (Holocene)

Fluvial sand, silt and gravel of variable thickness deposited by streams in floodplains, valley bottoms, and fans: includes Qua (young alluvium), Qoa (older alluvium), Quv (deposits of upper valley terraces) of Newcomb (1965); Qaf (alluvial fan deposits) and Qafo (older alluvial fan deposits) of Rigby and Othberg (1979).

Qgf ≶ Qt

Glaciofluviatile Deposits and Touchet Beds (Pleistocene)

Qgf - Sand and gravel deposits of high energy environments of catastrophic Pleistocene floods: includes Qu (glaciofluviatile deposits, undifferentiated) of Newcomb (1965); Qhp (Pasco Gravels) of Rockwell (1979); and Qfg (catastrophic flood gravels) of Rigby and Othberg (1979).
Qt - Silt and sand with stringers of sand and gravel deposited in low energy environments of Pleistocene floods (Touchet Beds of Flint, 1938): includes Qt (Touchet Beds) of Newcomb (1965); and Qht (Touchet Beds) of Rigby and Othberg (1979).

Note: Qt undifferentiated from Qgf in Plate 1 (Pendleton quadrangle).

Qts

Plio-Pleistocene Sedimentary Rocks

Cobbles, gravel, and boulders of basalt with silt and sand matrix: includes Qcq (old gravel and clay), Qr (Ringold Formation) of Newcomb (1965); Trs, Trc, Trf (Ringold Formation) of Rockwell (1979); and Tr (Ringold Formation) of Rigby and Othberg (1979). Also locally includes waterlain tuffs and tuffaceous sandstones; equivalent to the Dalles Formation, post-basalt sediments of Ellensburg Formation and Ringold Formation.

Ty

Columbia River Basalt Group
Yakima Basalt Subgroup (Miocene)

Tholeiitic basalt flows of the Saddle Mountains, Wanapum and Grande Ronde Formations. Locally includes talus, colluvium and thin loess deposits which overlie the basalt flows. Individual members are identified as follows:

Tysm - Saddle Mountain Basalt Formation (undifferentiated)
- Tylm - Lower Monumental Member
- Tyih - Ice Harbor Member
- Tyem - Elephant Mountain Member
- Typo - Pomona Member (includes Esquatzel member)
- Tyum - Umatilla Member (includes Wilbur Cr. member)

Tyw - Wanapum Basalt Formation (undifferentiated)
- Typr - Priest Rapids Member
- Tyro - Roza Member
- Tyfs - Frenchman Springs
  - Tydo - Dodge flow of Eckler Mountain Member

Tygr - Grande Ronde Basalt Formation, (undifferentiated) Includes flow of N1, N2, R1 and R2 magnetic polarities.

pT

Pre-Tertiary

Pre-Tertiary rocks, undifferentiated (Precambrian through Mesozoic) metamorphic and plutonic rocks which are locally exposed below the Columbia River Basalt flows: includes TpCr (rocks older than basalt of the Columbia River Group) of Newcomb (1970); TMzg, (plutonic rocks), MzPzm (metamorphic rocks) Rockwell (1979); and pm (pre-Miocene rocks, undifferentiated) of Rigby and Othberg (1979).

NOTES

CONTACTS MODIFIED FROM CARR AND WALDRON (1954)

units and petrologic ... late Olo ... Fecwell

... streams ... and alluvium), ... of Newcomb ... alluvial fan deposits)

... catastrophic ... undifferen- ... (1979); and ... (1979). ... in low ... 1978); ... beds) of

U and D indicate sense of apparent vertical offset.

Major fault or fault zone

Strike slip; parallel arrows indicates sense of slip

Apparent strike slip; double ended arrow indicates sense unknown.

Apparent dip slip; ball on downthrown side.

Barb indicates direction of dip and degree of dip where known. Arrow indicates rake of striae and degrees of rake.

Thrust fault; sawteeth on upper plate

FOLDS: Solid where exposed, dashed where inferred, dotted where covered, queried where questionable. Arrow shows direction of plunge if any.

Anticline

Syncline

Monocline; arrow points in direction of decreasing dip

Monocline; arrow points in direction of increasing dip

Ty Dike

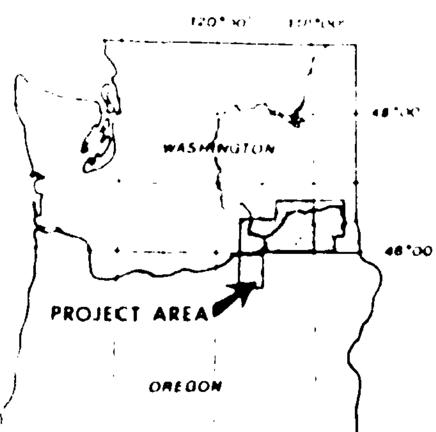
Horizontal bedding

Measured strike and dip

Apparent strike and dip

Geologic cross-section

VICINITY MAP



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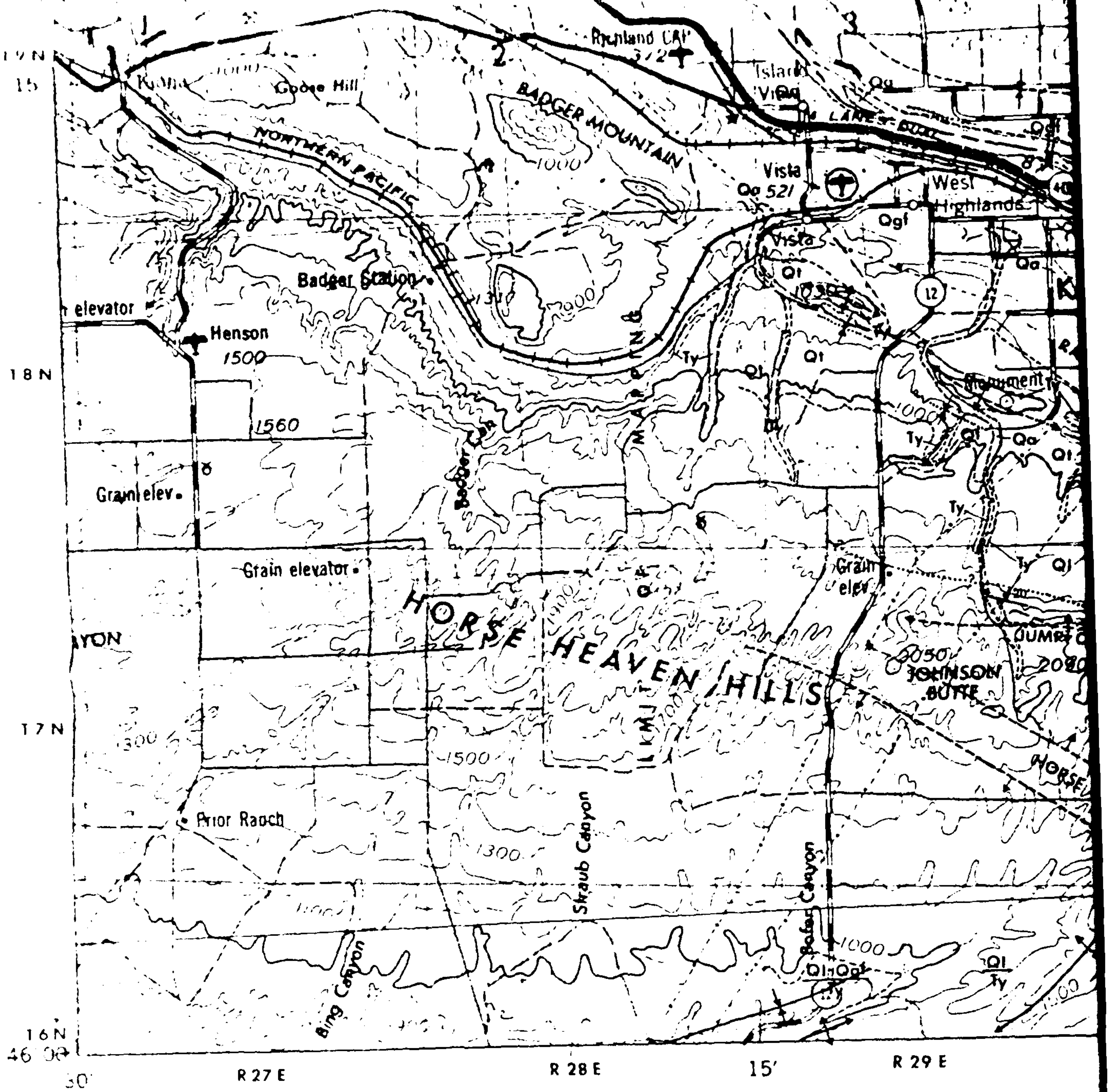

Richland CAP
Goose Hill
BADGER MOUNTAIN
NORTHERN PACIFIC
Island View
Vista
West Highlands
Badger Station
Henson
elevator
Grain elev.
Grain elevator
HORSE HEAVEN HILLS
JOHNSON BUTTE
Monument
Prior Ranch
Skaub Canyon
Bing Canyon
Bofer Canyon
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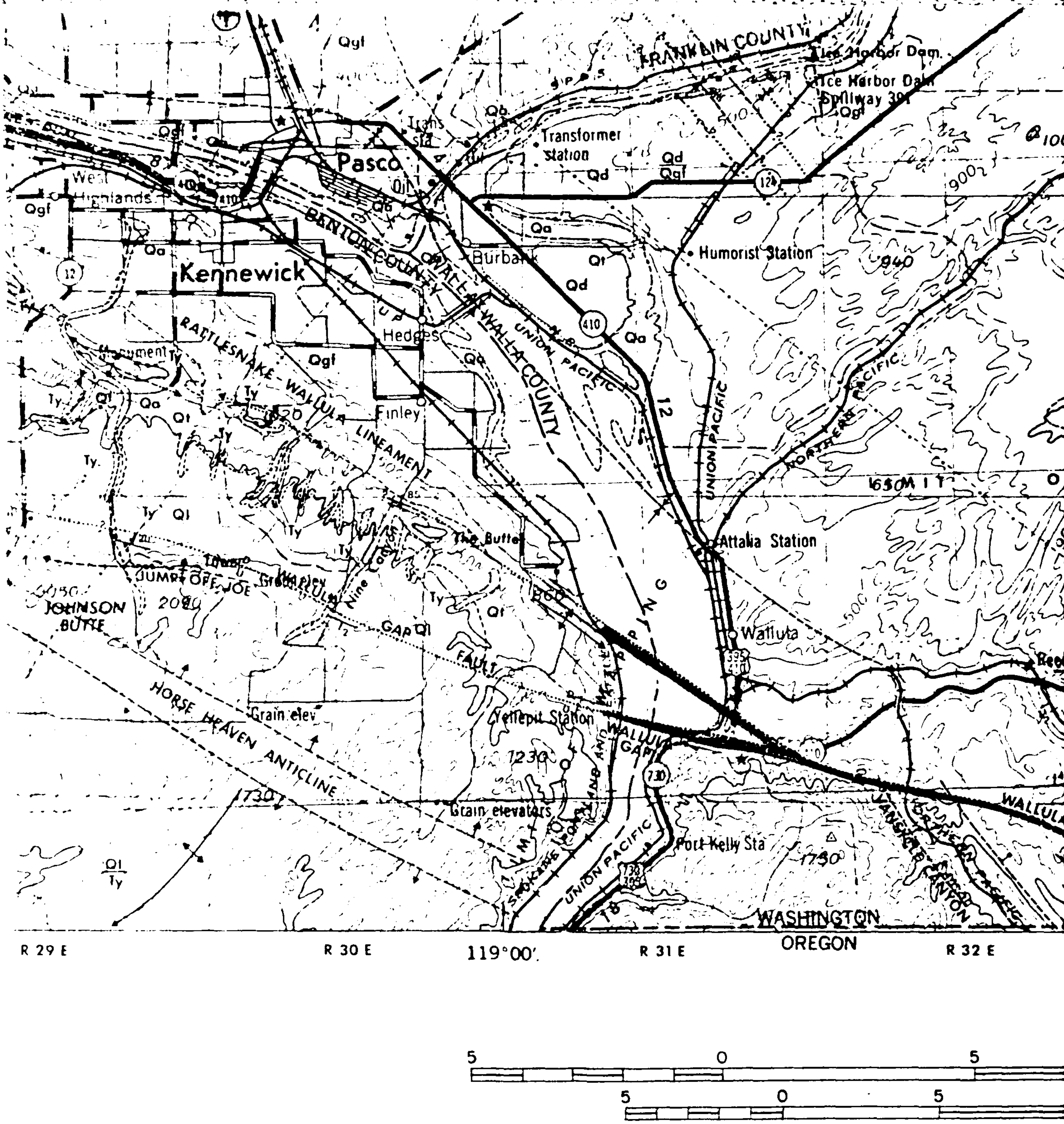
R 29 E

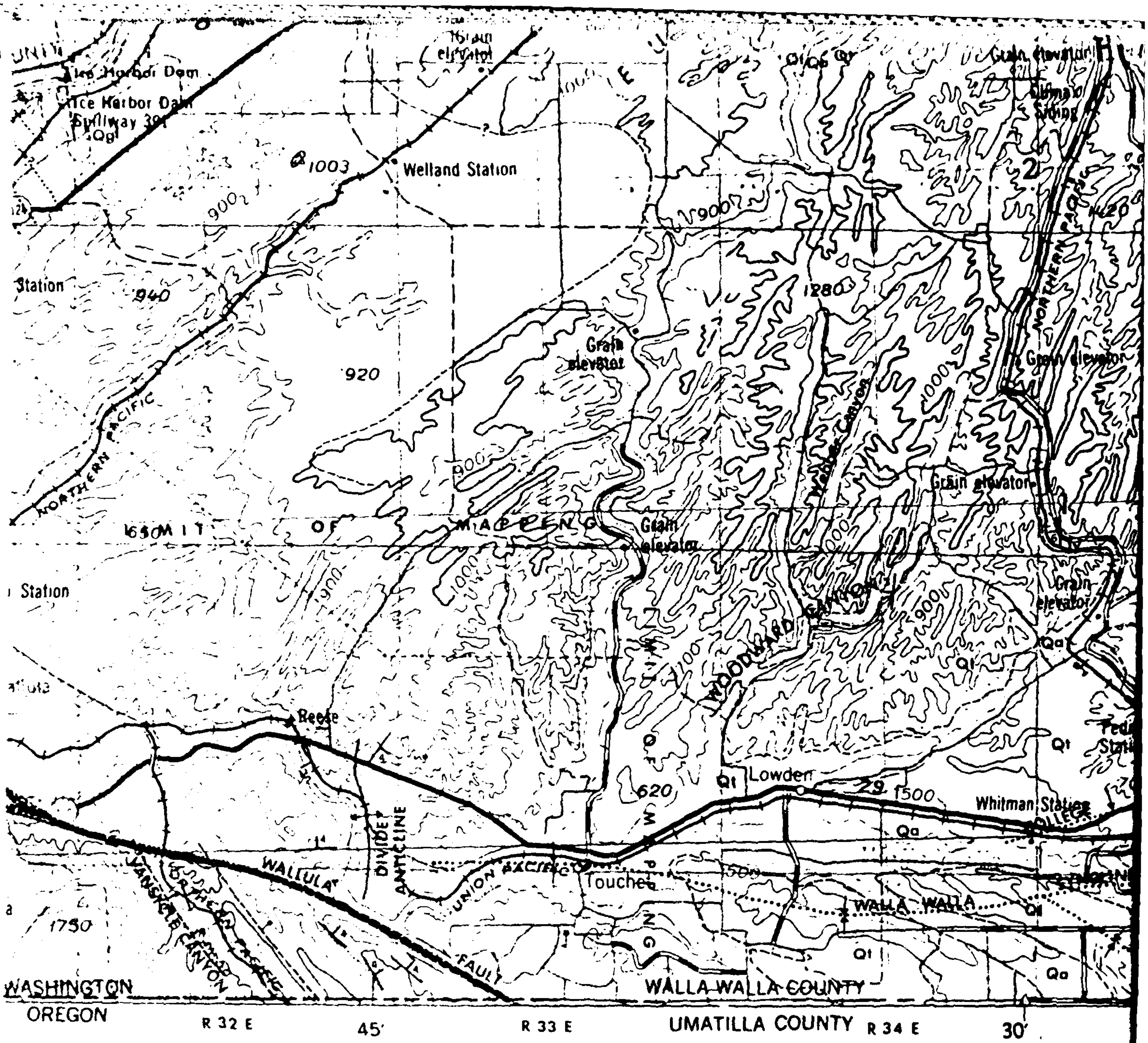
15

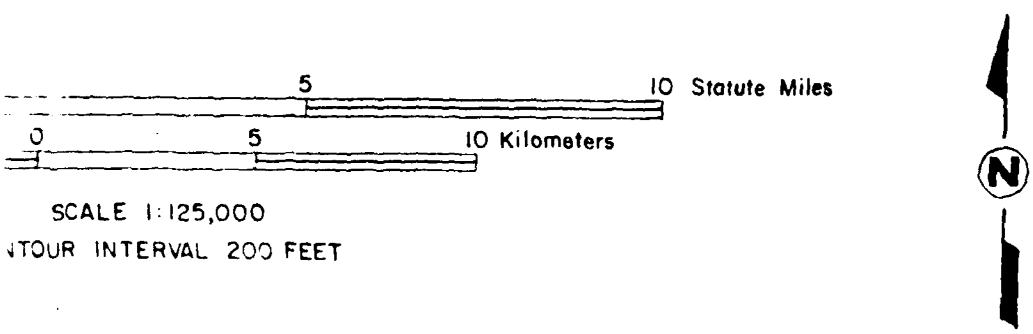


SCALE 1:125,000

CONTOUR INTERVAL 200 FEET

16





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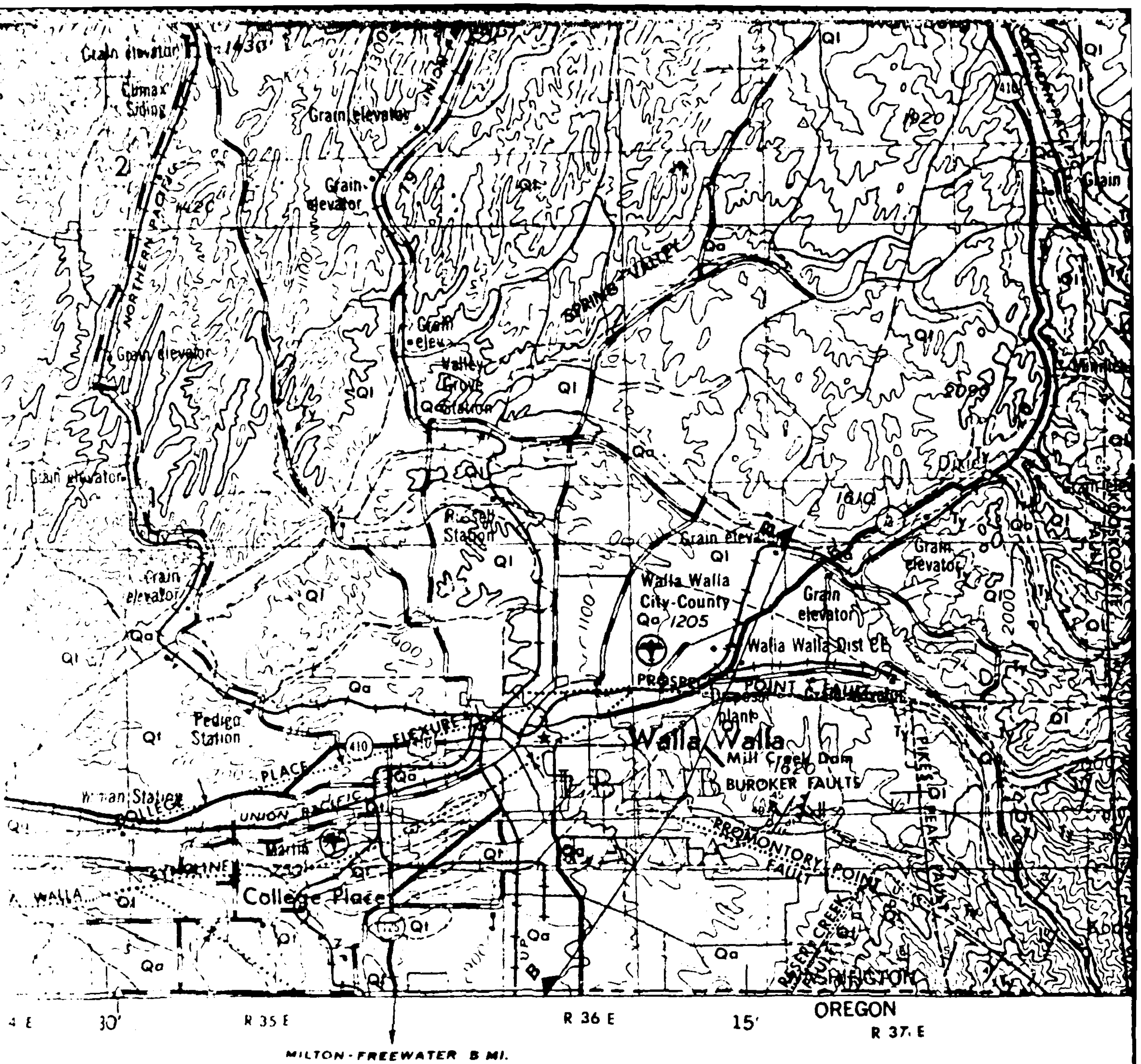
NTOUR INTERVAL 200 FEET

17


Grain elevator
Climax Siding
Grain elevator
Grain elevator
NORTHERN PACIFIC
UNION
SPRING VALLEY
Grain elevator
Valley Grove Station
Grain elevator
Russell Station
Grain elevator
Walla Walla City-County
1205
Grain elevator
Walla Walla Dist CE
PROSPECT POINT FAULT
Disposal plant
Pedigo Station
FLEXURE
410
Walla Walla
Mill Creek Dam
1820
BUROKER FAULTS
Whitman Station
COLLEGE PLACE
UNION PACIFIC
PROMONTORY POINT FAULT
PIKES PEAK FAULT
Martin
College Place
WALLA WALLA
BASKET CREEK FAULT
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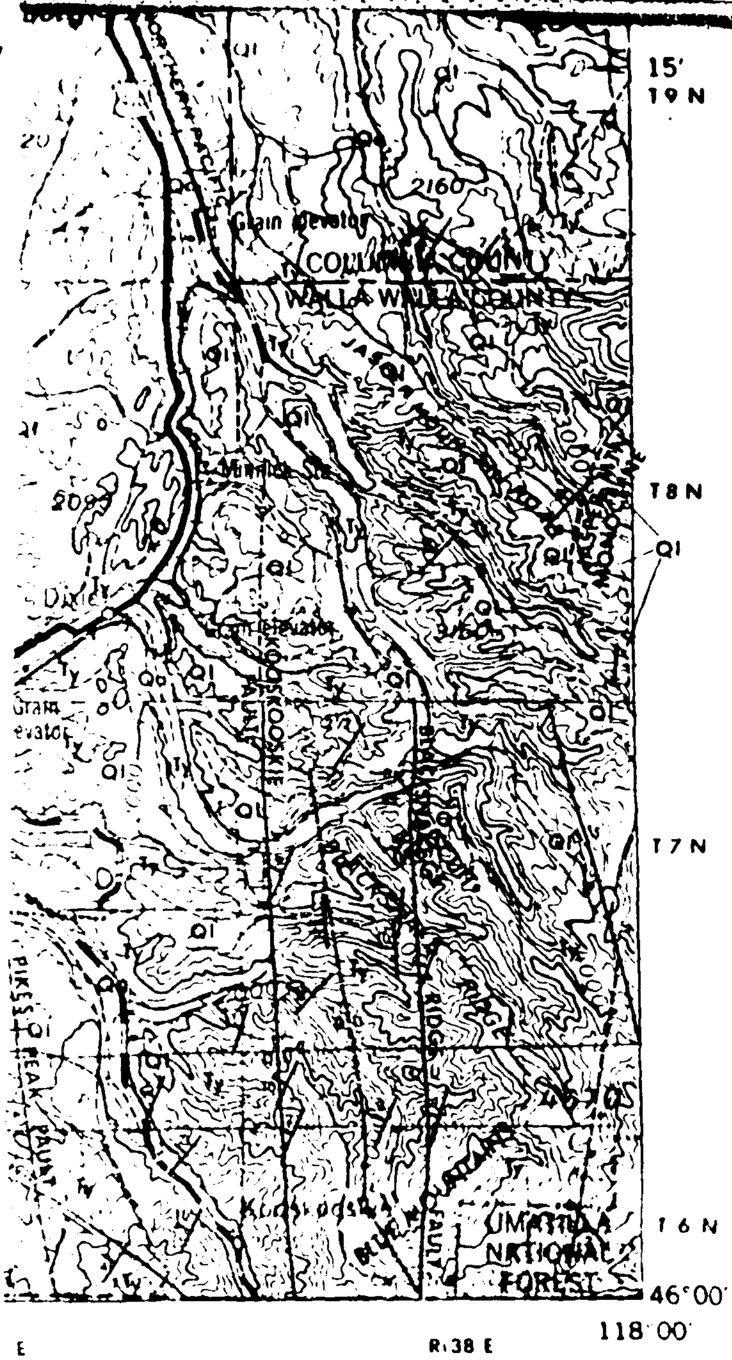

Plio-Pleistocene Sedimentary

Cobbles, gravel, and boulders of basalt with silt and
cludes Qcq (old gravel and clay), Qr (Ringold Formati
(1965); Trs, Trc, Trf (Ringold Formation) of Rockwell
(Ringold Formation) of Rigby and Othberg (1979). Als
waterlain tuffs and tuffaceous sandstones; equivalent
Formation, post-basalt sediments of Ellensburg Format
Formation.

Ty

Columbia River Basalt Group
Yakima Basalt Subgroup (Miocen

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deposits which overlie the basalt flows. Individual
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  - Tyem - Elephant Mountain Member
  - Typo - Pomona Member (includes Esquatzel memb
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- Tyw - Wanapum Basalt Formation (undifferentiated)
  - Typr - Priest Rapids Member
  - Tyro - Roza Member
  - *Tyfs - Frenchman Springs*
    - Tydo - Dodge flow of Eckler Mountain Membe
- Tygr - Grande Ronde Basalt Formation, (undifferentia
  of N1, N2, R1 and R2 magnetic polarities.

pT

Pre-Tertiary

Pre-Tertiary rocks, undifferentiated (Precambrian th
metamorphic and plutonic rocks which are locally exp
Columbia River Basalt flows: includes TpCr (rocks ol
of the Columbia River Group) of Newcomb (1970); TMzg
MzPzm (metamorphic rocks) Rockwell (1979); and pm (
undifferentiated) of Rigby and Othberg (1979).

NOTES

GEOLOGIC CONTACTS MODIFIED FROM GARD AND WALDRO
TRIMBLE (1954), WALDRON AND GARD (1954 & 1955),
& 1970), MOLENAAR (1968), KIENLE AND NEWCOMB (1
AND OTHERS (1977 & 1979), KIENLE AND OTHERS (19
OTHBERG (1979) AND ROCKWELL (1979).

GEOLOGIC AND TECTONIC RECONNAISSANCE BY C.F. KI
HAMILL, K.E. LITE AND G.L. PETERSON.

BASE MAP FROM U.S. CORPS OF ENGINEERS, ARMY MAP
1:250,000 SCALE.

19

boulders of basalt with silt and sand matrix; in
vel and clay). Qr (Ringold Formation) of Newcomb
rl (Ringold Formation) of Rockwell (1979); and Tr
of Rigby and Othberg (1979). Also locally includes
tuffaceous sandstones; equivalent to the Dalles
alt sediments of Ellensburg Formation and Ringold

Ty

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Yakima Basalt Subgroup (Miocene)

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Monumental Member
Harbor Member
ant Mountain Member
a Member (includes Esquatzel member)
illa Member (includes Wilbur Cr. member)
alt Formation (undifferentiated)
st Rapids Member
Member
hman Springs
one flow of Eckler Mountain Member
e Basalt Formation, (undifferentiated) Includes flow
polarities.

pT

Pre-Tertiary

undifferentiated (Precambrian through Mesozoic)
tonic rocks which are locally exposed below the
alt flows. Includes TrCr (rocks older than basalt
ver Group) of Newcomb (1970); TMzg, (plutonic rocks),
rocks Rockwell (1979); and pm (pre-Miocene rocks,
Rigby and Othberg (1979).

Syncline

Monocline; arrow points in direction of decreasing dip

Monocline; arrow points in direction of increasing dip

Ty Dike

Horizontal bedding

Measured strike and dip

Apparent strike and dip

Geologic cross-section

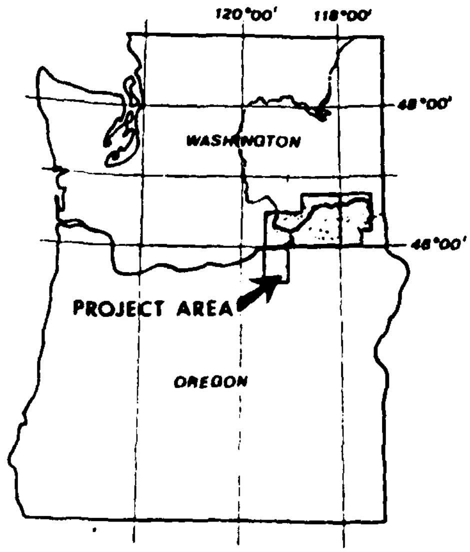
NOTES

FROM GARD AND WALDRON (1954),
WALDRON AND GARD (1954 & 1955), NEWCOMB (1965
(1969), KIENLE AND NEWCOMB (1973), SWANSON
& 1979), KIENLE AND OTHERS (1979), RIGBY AND
AND ROCKWELL (1979).

TECTONIC RECONNAISSANCE BY C.F. KIENLE, JR., M.L.
AND G.L. PETERSON.

CORPS OF ENGINEERS, ARMY MAP SERVICE,

VICINITY MAP



FOUNDATION SCIENCES, INC.
PORTLAND, OREGON

U.S. CORPS OF ENGINEERS
DACW67-80-C-0125

RECONNAISSANCE GEOLOGIC AND TECTONIC MAP
OF THE LOWER SNAKE RIVER CORRIDOR
AND THE MILL CREEK-KOOSKOOSKIE AREA, WASHINGTON

SCALE	1:125,000	DRN	M KELLY	NO.	PLATE 2
DATE	NOV. 1980	CHK/APP	C.F. KIENLE	SHEET	

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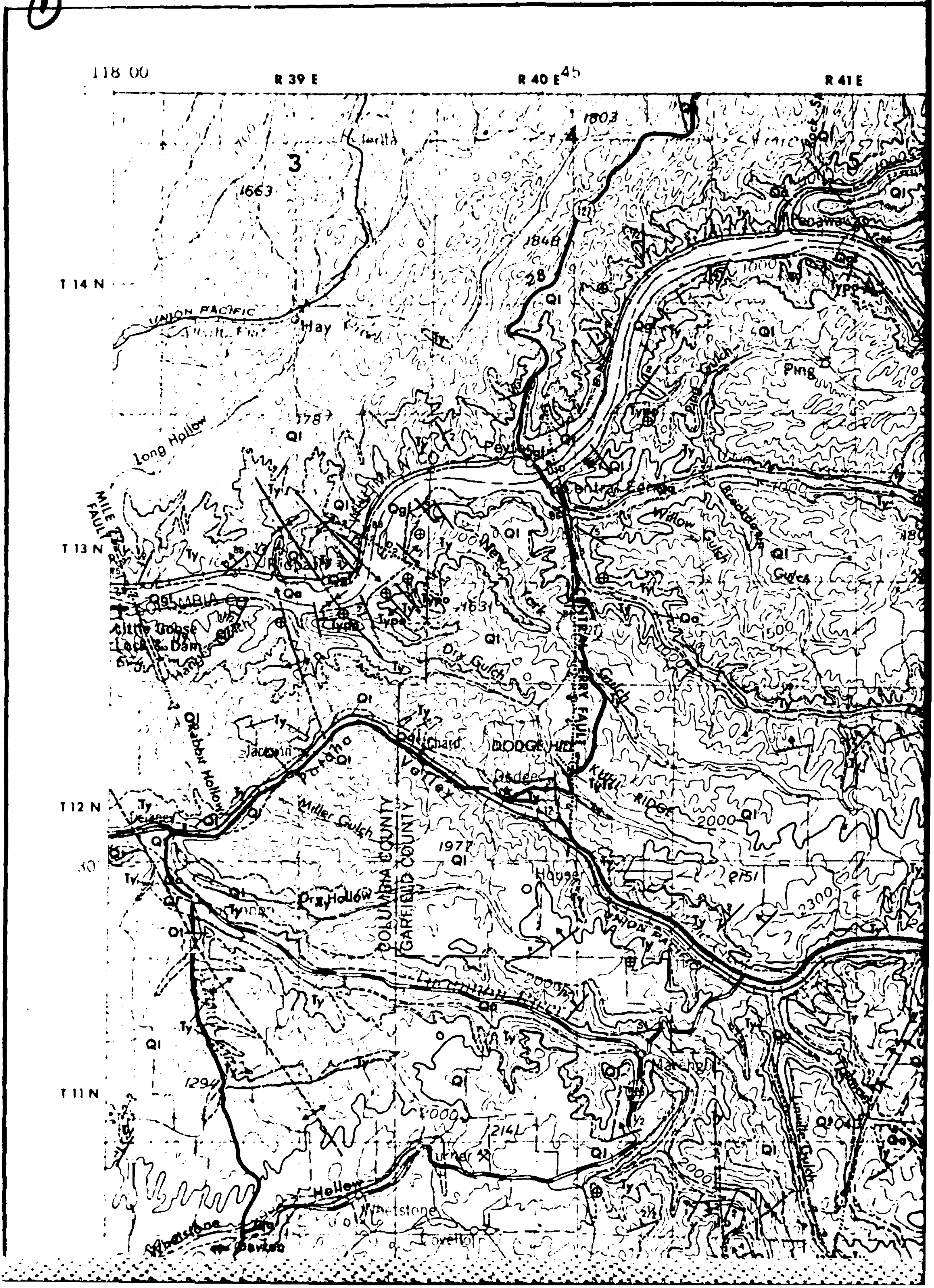

118 00
R 39 E
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45
R 41 E
T 14 N
T 13 N
T 12 N
T 11 N
30'
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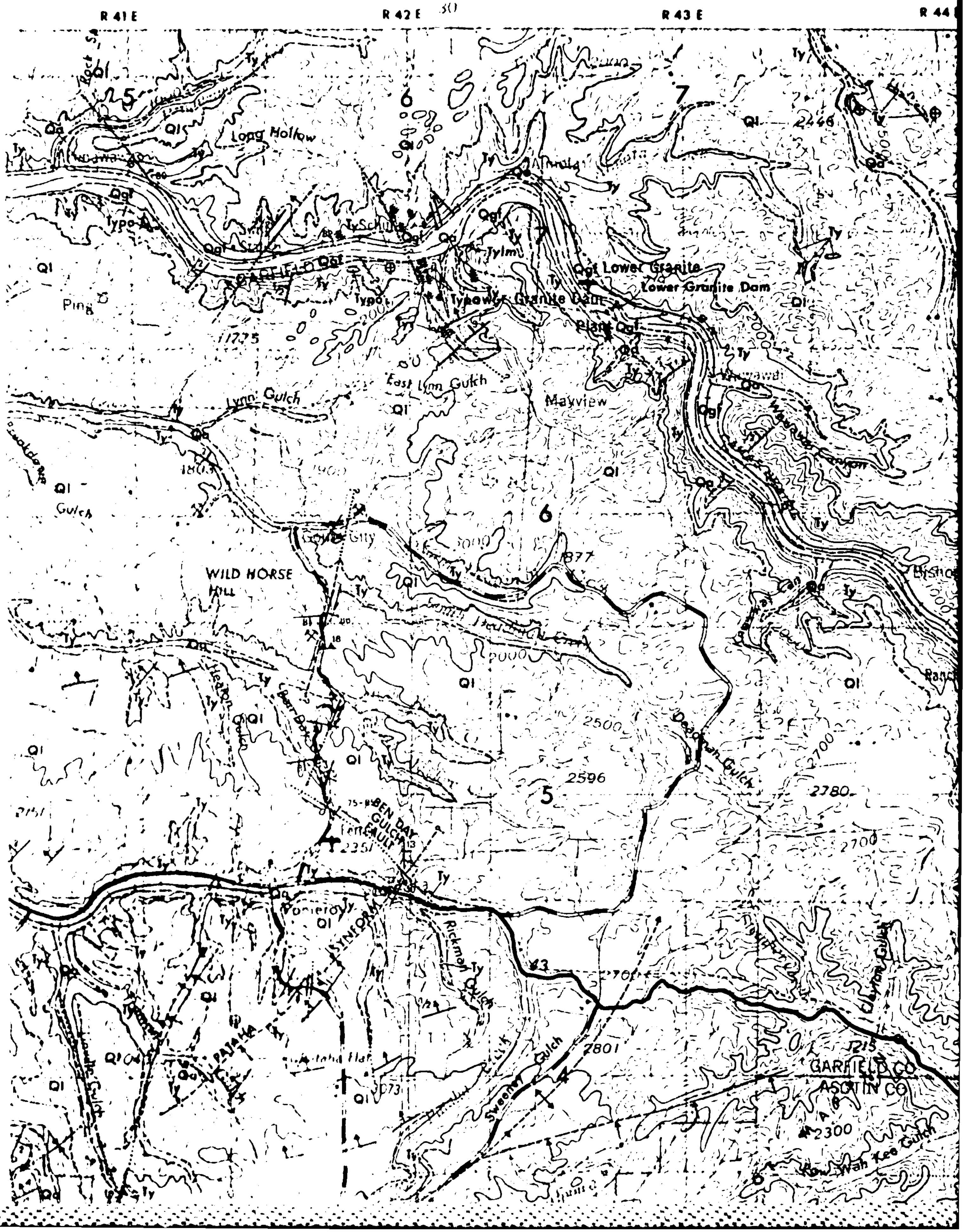
1848
1787
1631
1977
2151
2300
1294
2000
2146
UNION PACIFIC
Hay
Long Hollow
MILE FAULT
Peyton
Central Ferry
Willow Gulch
Ping
Gulch
Pedaway
New York
Dry Gulch
Little Goose Lock & Dam
Rabbit Hollow
Jackson
Pataha
Valley
Chard
DODGE HILL
Dodge
KUEL RIDGE
CENTRAL FERRY FAULT
Miller Gulch
COLUMBIA COUNTY
GARFIELD COUNTY
House
Dry Hollow
Hollow
Whetstone
Lovell
Turner
Marengo
Ql
Qa
Qgl
Ty
Typa

2



R 41 E
R 42 E
R 43 E
Long Hollow
Lower Granite
Lower Granite Dam
GARFIELD CO
Ping
East Lynn Gulch
Lynn Gulch
Mayview
Gulch
WILD HORSE HILL
Deadman Gulch
BEN DAY GULCH FAULT
Pomeroy
SYNFORM
PATAHA
Rickman Gulch
Sweeney Gulch
Clayton Gulch
GARFIELD CO.
ASOTIN CO.
Kow Wah Kee Gulch
2596
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2700
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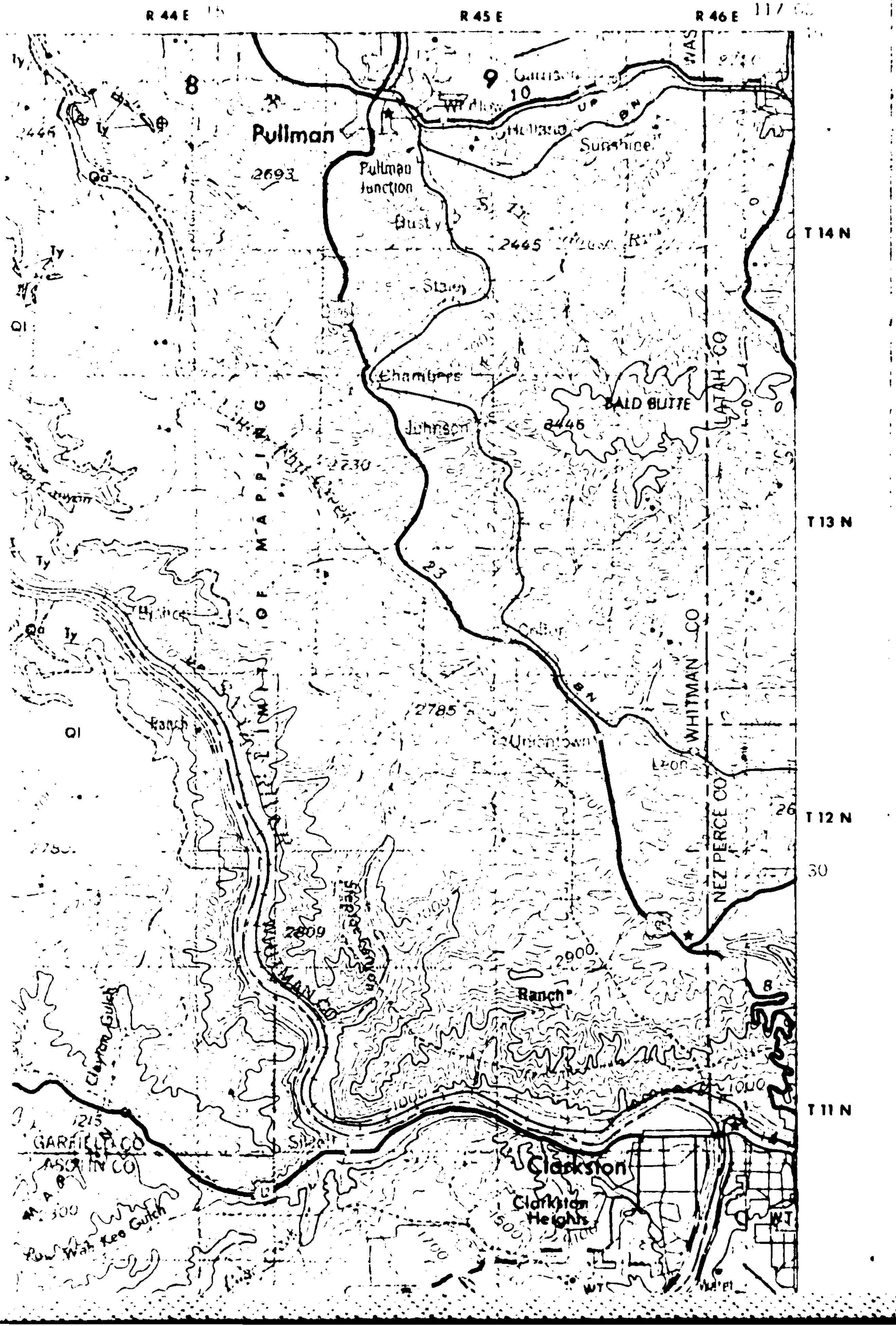
2300

3



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4

GEOLOGIC UNITS

Qd

Sand Dunes (Holocene)

Active and stabilized eolian dunes of basaltic and quartzitic, medium- to fine-grained sand: includes Qd (dune sand) of Rockwell (1979); Qda (active sand dunes) and Qds (stabilized sand dunes) of Rigby and Othberg (1979).

Ql

Loess (Holocene)

Eolian silt and fine sand with volcanic ash units and petrocalcic horizons derived largely from erosion of Qgf and Qt: includes Qlu (loess), Qp (Palouse Formation) of Newcomb (1965); Ql (Loess) of Rigby and Othberg (1979); and Qts (Palouse Formation) of Rockwell (1979).

Qa

Alluvium (Holocene)

LEGEN

GEOLOGIC CONTACTS

$\frac{Ql}{Ty}$ Unit of upper
of lower symb

$\frac{Ql-Qgf}{Ty}$ Undifferentia
lower units

FAULTS: Solid where exp
inferred, dotted where c
where questionable.

U and D denot
vertical offs

Major fault c

Strike slip;
dicates sens

5

Qlu

ockwell

LEGEND

GEOLOGIC CONTACTS

$\frac{Ql}{Ty}$ Unit of upper symbol mantles unit of lower symbol

$\frac{Ql-Qgf}{Ty}$ Undifferentiated units mantle lower units

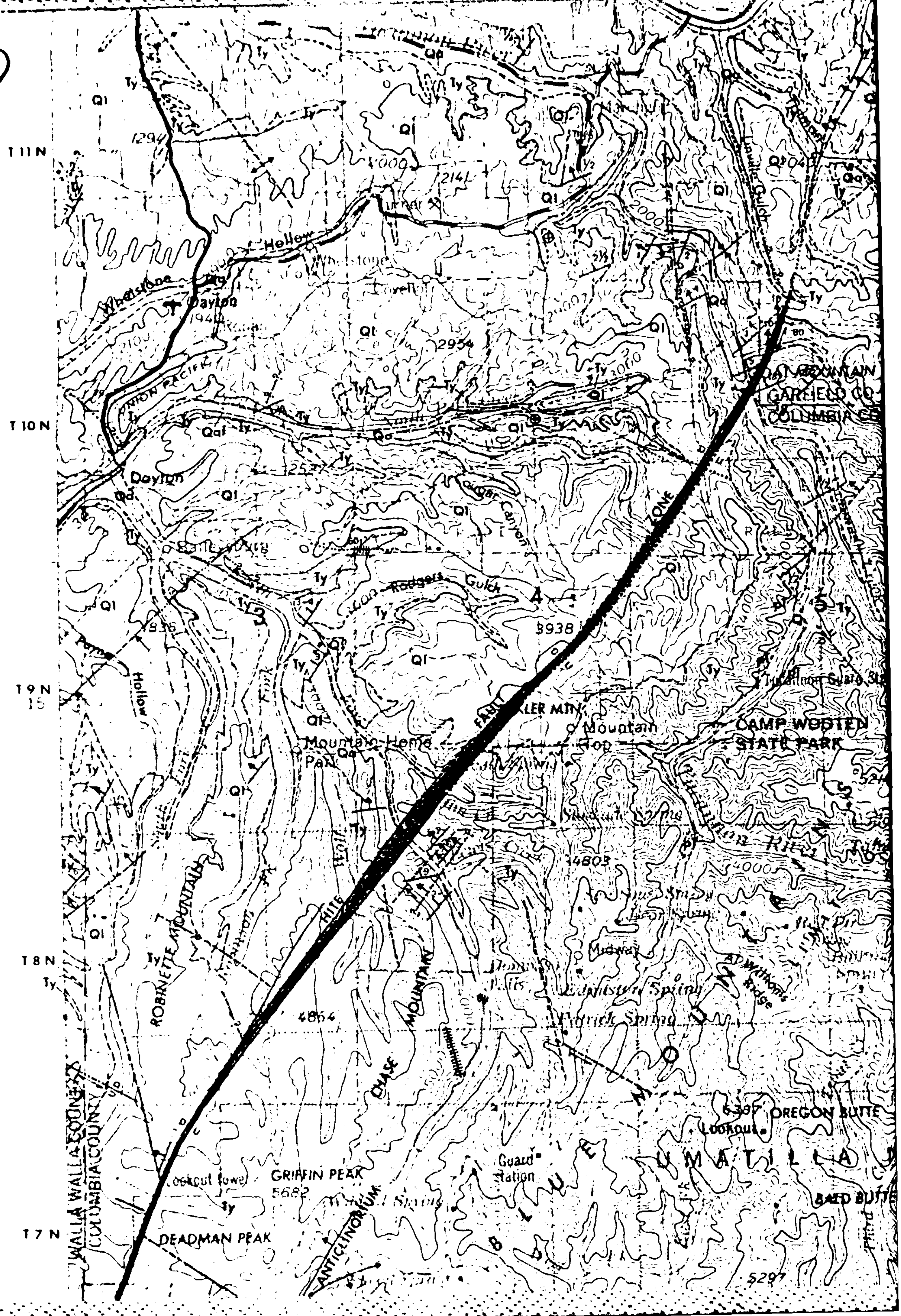
FAULTS: Solid where exposed, dashed where inferred, dotted where covered, queried where questionable.

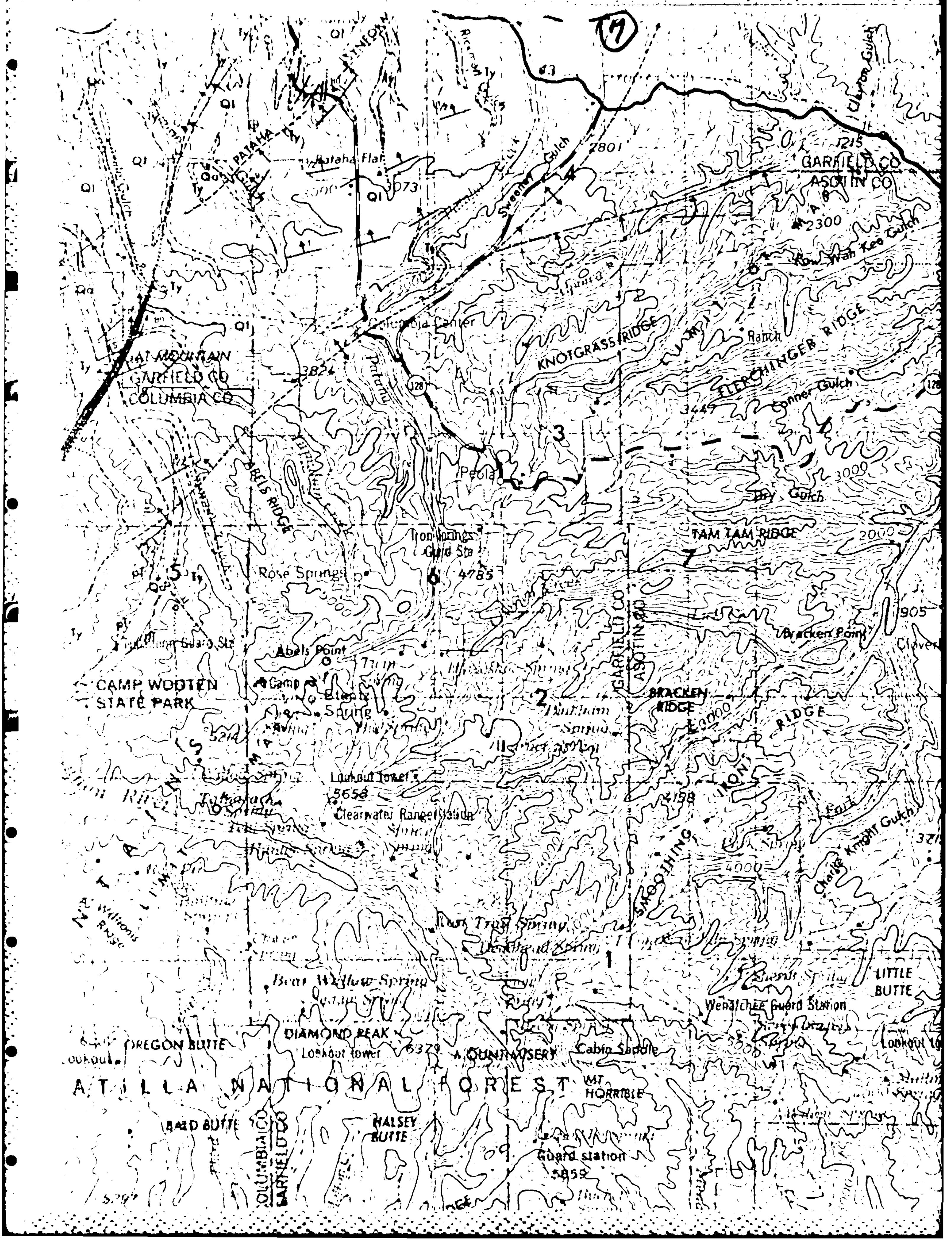
U and D denote sense of apparent vertical offset.

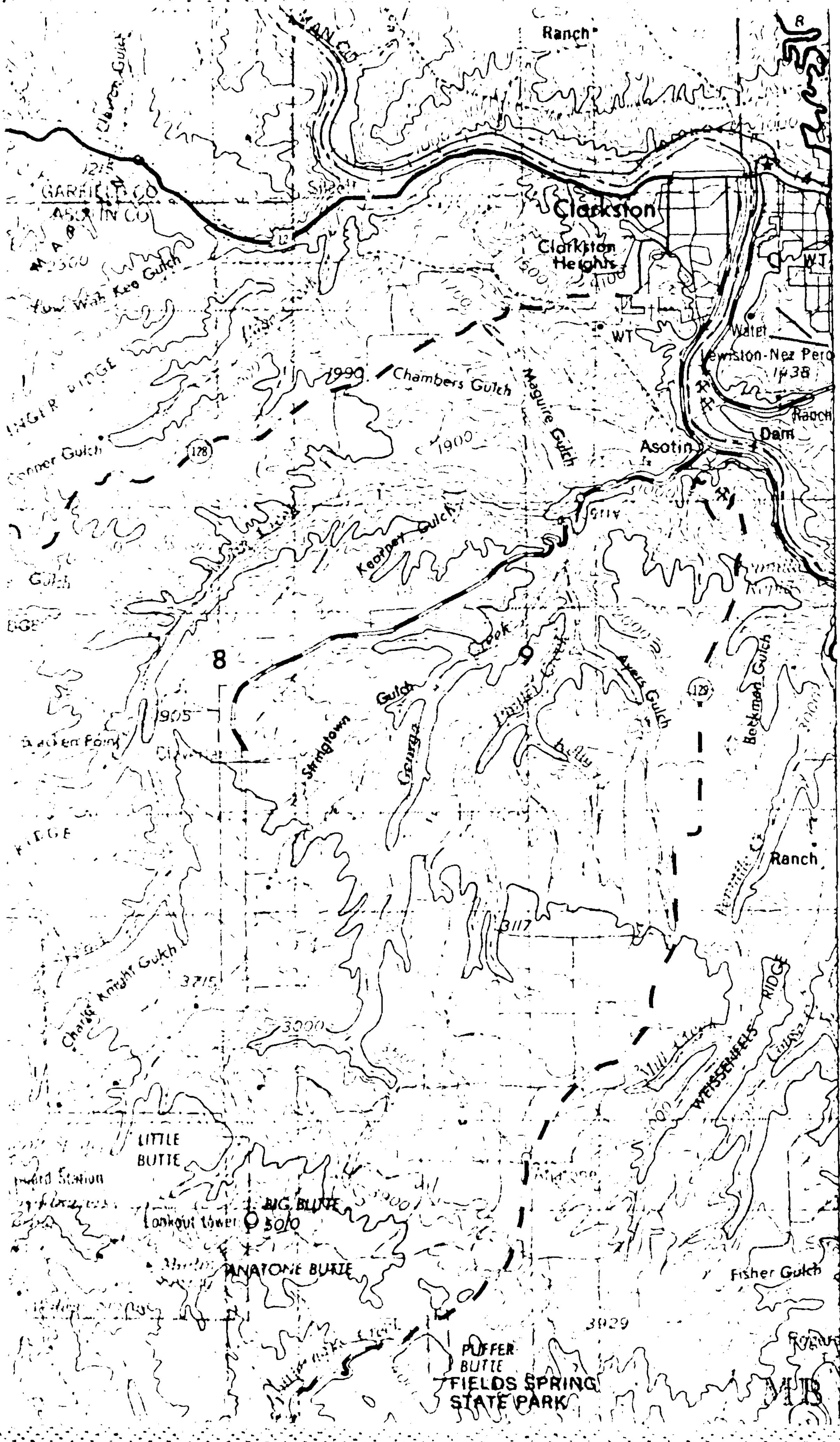
Major fault or fault zone

Strike slip; parallel arrows in-

6


T11N
T10N
T9N
T8N
T7N
Hollow
Whetstone
Dayton
Lovell
2954
UNION PACIFIC
Dayton
Rodgers Gulch
3938
Mountain Home Park
FAULT
MOUNTAIN
GARFIELD CO
COLUMBIA CO
CAMP WOOTEN STATE PARK
Mountain Top
4803
ZONE
ROBINETTE MOUNTAIN
CHASE MOUNTAIN
4864
Midway
Patrick Spring
OREGON BUTTE
Lookout
6387
UMATILLA
BLUE
GRIFFIN PEAK
5682
Lookout Tower
Guard Station
DEADMAN PEAK
ANTICLINORIUM
WALLA WALLA COUNTY
COLUMBIA COUNTY
BALD BUTTE
5297
Ql
Ty
Qal


17
PATAHA
Pataha Flat
3073
2801
Sweeney Gulch
GARFIELD CO
ASOTIN CO
2300
Pow Wah Kee Gulch
Columbia Center
3824
GARFIELD CO
COLUMBIA CO
KNOTGRASS RIDGE
Ranch
FLERCHINGER RIDGE
Conner Gulch
3449
Peola
3000
Dry Gulch
ABELS RIDGE
Iron Springs
Guard Sta
TAM TAM RIDGE
2000
Rose Springs
4785
GARFIELD CO
ASOTIN CO
Bracken Point
Abels Point
CAMP WOOTEN
STATE PARK
BRACKEN
RIDGE
RIDGE
Lookout tower
5658
Clearwater Ranger Station
SMOOTHING IRON
Charlie Knight Gulch
4000
Bear Wallow Spring
LITTLE
BUTTE
Wenatchee Guard Station
DIAMOND PEAK
OREGON BUTTE
Lookout tower
Cabin Saddle
ATILLA NATIONAL FOREST
MT.
HORRIBLE
BALD BUTTE
COLUMBIA CO
GARFIELD CO
HALSEY
BUTTE
Guard station
5859



Ranch
T 11 N
GARFIELD CO
ASOTIN CO
12
Clarkston
Clarkston Heights
WT
Water
Lewiston-Nez Perce
1438
Ranch
Dam
Tow Wah Kee Gulch
Chambers Gulch
Maguire Gulch
1990
1900
Conner Gulch
128
Asotin
T 10 N
Kearney Gulch
Gulch
8
9
Creek
Gulch
Stringtown
Ayers Gulch
129
Beckman Gulch
1905
T 9 N
15
Ranch
3117
Charlie Knight Gulch
3715
3000
WEISSENFELS RIDGE
T 8 N
LITTLE BUTTE
Lookout tower
BIG BUTTE
5010
ANATONE BUTTE
Fisher Gulch
3929
PUFFER BUTTE
FIELDS SPRING STATE PARK
T 7 N

Active and stabilized eolian dunes of basaltic and quartzitic, medium- to fine-grained sand: includes Qd (dune sand) of Rockwell (1979); Qda (active sand dunes) and Qds (stabilized sand dunes) of Rigby and Othberg (1979).

Ql

Loess (Holocene)

11 N

Eolian silt and fine sand with volcanic ash units and petrocalcic horizons derived largely from erosion of Qgf and Qt: includes Qlu (loess), Qp (Palouse Formation) of Newcomb (1965); Ql (loess) of Rigby and Othberg (1979); and Qts (Palouse Formation) of Rockwell (1979).

Qa

Alluvium (Holocene)

Fluvial sand, silt and gravel of variable thickness deposited by streams in floodplains, valley bottoms, and fans: includes Qua (young alluvium), Qoa (older alluvium), Quv (deposits of upper valley terraces) of Newcomb (1965); Qaf (alluvial fan deposits) and Qafo (older alluvial fan deposits) of Rigby and Othberg (1979).

10 N

Qgf ≷ Qt

Glaciofluviatile Deposits and Touchet Beds (Pleistocene)

Qgf - Sand and gravel deposits of high energy environments of catastrophic Pleistocene floods: includes Qu (glaciofluviatile deposits, undifferentiated) of Newcomb (1965); Qhp (Pasco Gravels) of Rockwell (1979); and Qfg (catastrophic flood gravels) of Rigby and Othberg (1979).
Qt - Silt and sand with stringers of sand and gravel deposited in low energy environments of Pleistocene floods (Touchet Beds of Flint, 1938): includes Qt (Touchet Beds) of Newcomb (1965); and Qht (Touchet Beds) of Rigby and Othberg (1979).

Note: Qt undifferentiated from Qgf in Plate 1 (Pendleton quadrangle).

Qts

Plio-Pleistocene Sedimentary Rocks

9 N

Cobbles, gravel, and boulders of basalt with silt and sand matrix: includes Qcq (old gravel and clay), Qr (Ringold Formation) of Newcomb (1965); Trs, Trc, Trf (Ringold Formation) of Rockwell (1979); and Tr (Ringold Formation) of Rigby and Othberg (1979). Also locally includes waterlain tuffs and tuffaceous sandstones; equivalent to the Dalles Formation, post-basalt sediments of Ellensburg Formation and Ringold Formation.

Ty

Columbia River Basalt Group
Yakima Basalt Subgroup (Miocene)

Tholeiitic basalt flows of the Saddle Mountains, Wanapum and Grande Ronde Formations. Locally includes talus, colluvium and thin loess deposits which overlie the basalt flows. Individual members are identified as follows:

8 N

Tysm - Saddle Mountain Basalt Formation (undifferentiated)
- Tylm - Lower Monumental Member
- Tyih - Ice Harbor Member
- Tyem - Elephant Mountain Member
- Typo - Pomona Member (includes Esquatzel member)
- Tyum - Umatilla Member (includes Wilbur Cr. member)

Tyw - Wanapum Basalt Formation (undifferentiated)
- Typr - Priest Rapids Member
- Tyro - Roza Member
- Tyfs - Frenchman Springs
  - Tydo - Dodge flow of Eckler Mountain Member

Tygr - Grande Ronde Basalt Formation, (undifferentiated) Includes flow of N1, N2, R1 and R2 magnetic polarities.

pT

Pre-Tertiary

7 N

Pre-Tertiary rocks, undifferentiated (Precambrian through Mesozoic) metamorphic and plutonic rocks which are locally exposed below the Columbia River Basalt flows: includes TpCr (rocks older than basalt

Ql/Ty — Unit of up[...] of lower s[...]

Ql–Qgf/Ty — Undifferen[...] lower unit[...]

FAULTS: Solid where [...] inferred, dotted wher[...] where questionable.

U and D de[...] vertical o[...]

Major faul[...]

Strike sli[...] dicates se[...]

Apparent s[...] arrow indi[...]

Apparent d[...] thrown sid[...]

Barb indic[...] degree of [...] indicates [...] of rake.

Thrust fau[...] plate

FOLDS: Solid where ex[...] ferred, dotted where [...] questionable. Arrow [...] if any.

Anticline

Syncline

Monocline; [...] of decreas[...]

Monocline; [...] of increas[...]

Ty Dike

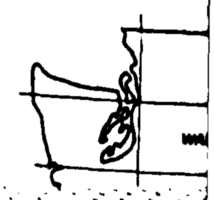
Horizontal

Measured s[...]

Apparent s[...]

Geologic c[...]

VICINI[...]



$\frac{Ql}{Ty}$ Unit of upper symbol mantles unit of lower symbol

$\frac{Ql-Qgf}{Ty}$ Undifferentiated units mantle lower units

FAULTS: Solid where exposed, dashed where inferred, dotted where covered, queried where questionable.

U D — U and D denote sense of apparent vertical offset.

Major fault or fault zone

Strike slip; parallel arrows indicates sense of slip

Apparent strike slip; double ended arrow indicates sense unknown.

Apparent dip slip; ball on downthrown side.

Barb indicates direction of dip and degree of dip where known. Arrow indicates rake of striae and degrees of rake.

Thrust fault; sawteeth on upper plate

FOLDS: Solid where exposed, dashed where inferred, dotted where covered, queried where questionable. Arrow shows direction of plunge if any.

Anticline

Syncline

Monocline; arrow points in direction of decreasing dip

Monocline; arrow points in direction of increasing dip

Ty Dike

Horizontal bedding

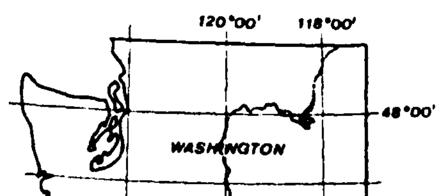
Measured strike and dip

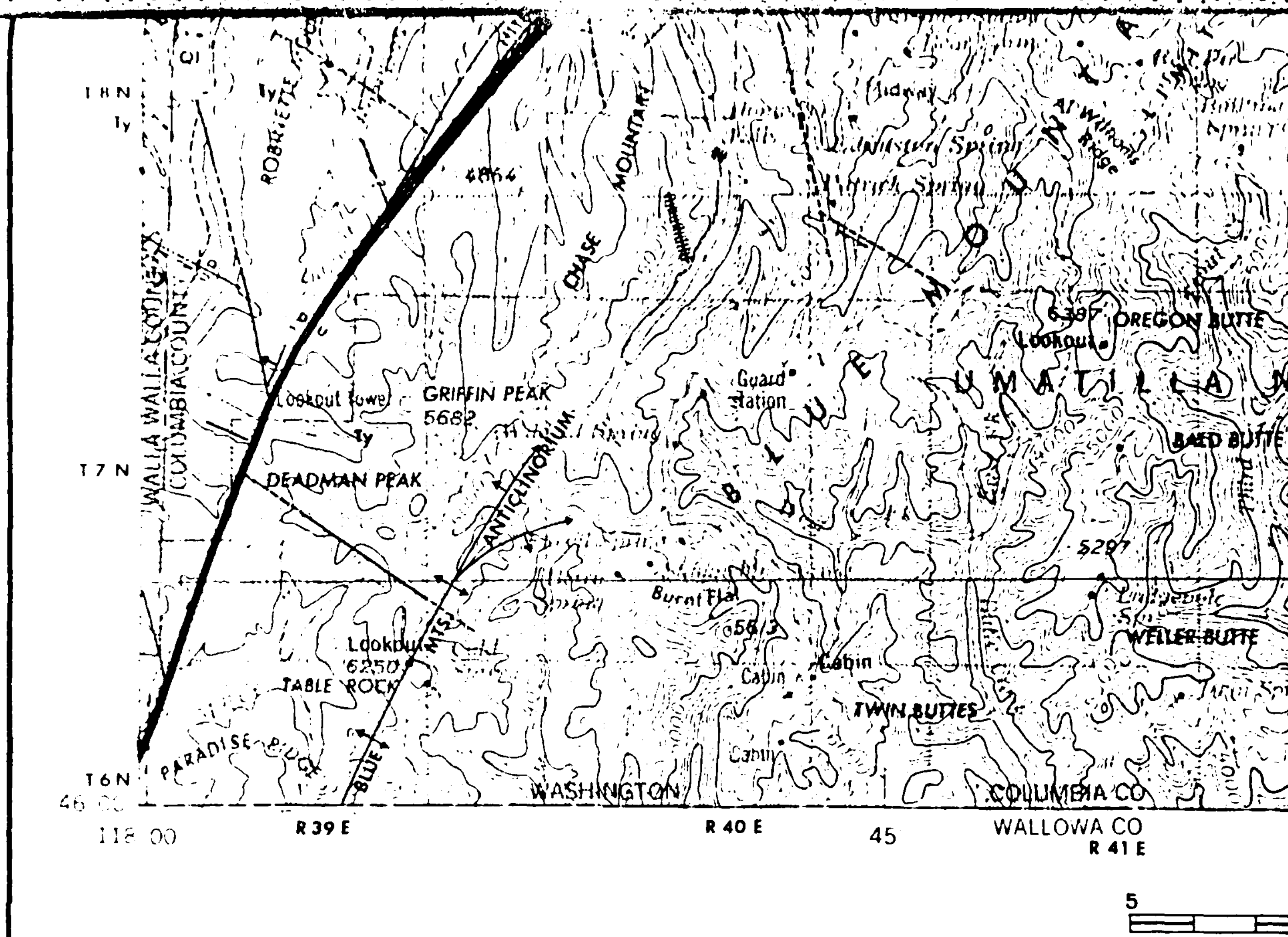
Apparent strike and dip

A A' Geologic cross-section

through Mesozoic)
exposed below the
older than basalt

VICINITY MAP





T 8 N
Ty
Ql
ROBBIETTE
4864
CHASE
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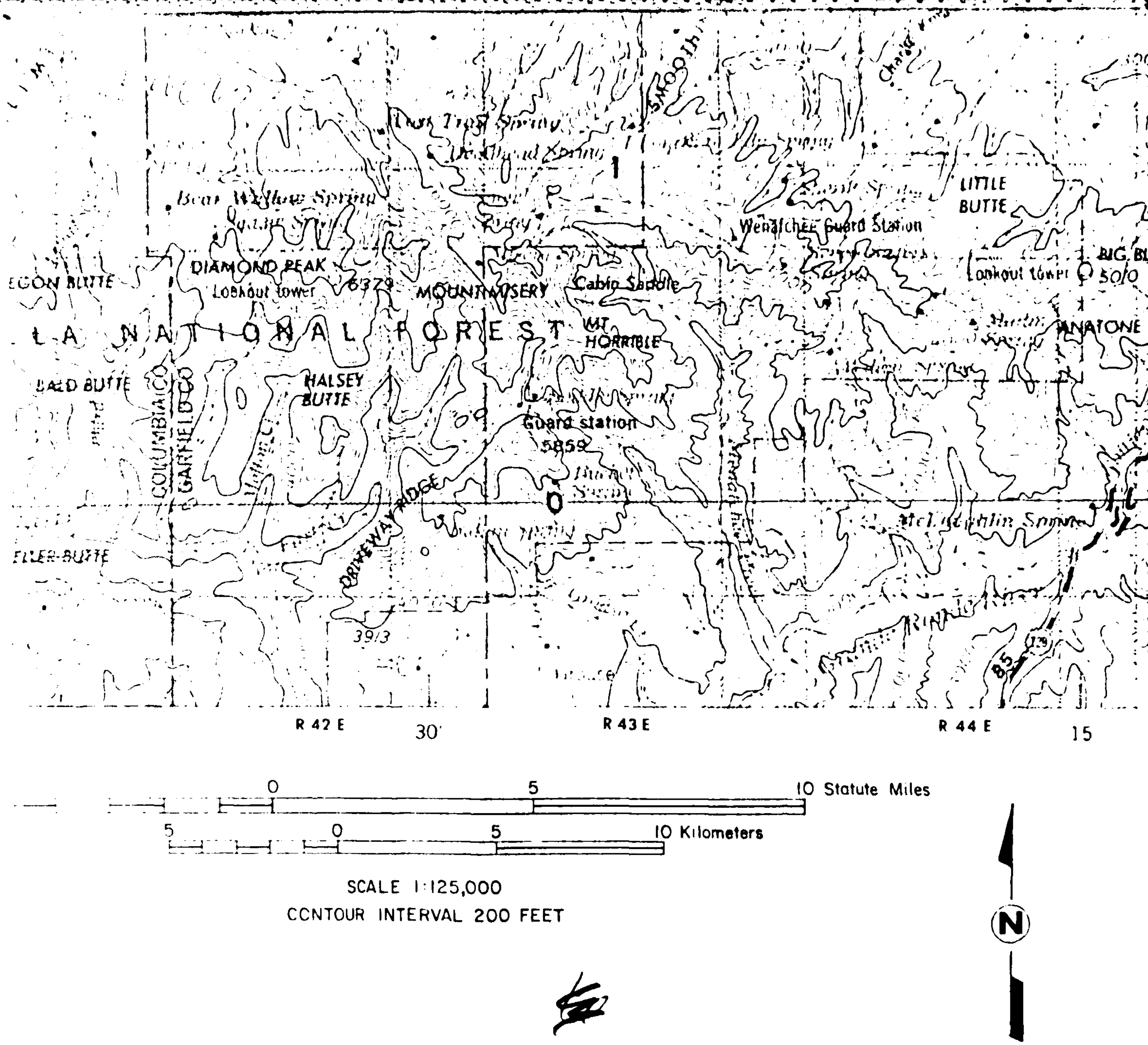
Midway
Al Williams Ridge
BLUE MOUNTAINS
6387
Lookout
OREGON BUTTE
UMATILLA N
WALLA WALLA COUNTY
COLUMBIA COUNTY
Lookout Tower
GRIFFIN PEAK
5682
ANTICLINORIUM
Guard Station
BALD BUTTE
T 7 N
DEADMAN PEAK
5297
Burnt Flat
Lookout
6250
TABLE ROCK
MTS.
BLUE
Cabin
WELLER BUTTE
TWIN BUTTES
T 6 N
PARADISE RIDGE
WASHINGTON
COLUMBIA CO
WALLOWA CO
118 00
R 39 E
R 40 E
45
R 41 E
5

11


LITTLE BUTTE
Wenatchee Guard Station
DIAMOND PEAK
Lookout tower
6379
MOUNT MISERY
Cabin Saddle
Lookout tower
5010
ANATONE
NATIONAL FOREST
MT. HORRIBLE
BALD BUTTE
HALSEY BUTTE
COLUMBIA CO
GARFIELD CO
Guard station
5859
DRIVEWAY RIDGE
3913
R 42 E
30'
R 43 E
R 44 E
15
0
5
10 Statute Miles
5
0
5
10 Kilometers
SCALE 1:125,000
CONTOUR INTERVAL 200 FEET
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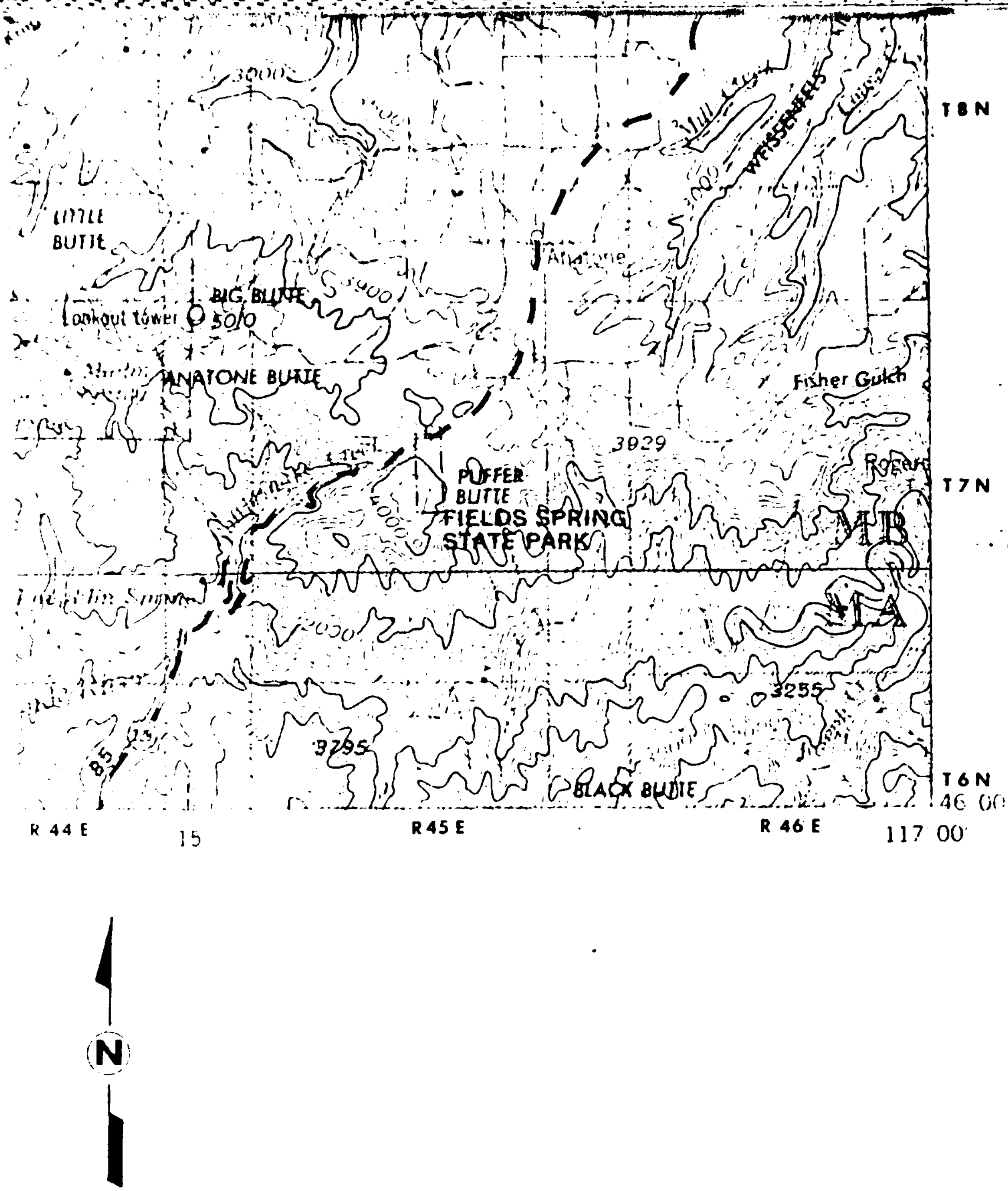
12



Tholeiitic ba
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identified as

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Tylm -
Tyih -
Tyem -
Typo -
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Tyw - Wanapu
Typr -
Tyro -
Tyfs -
Tyd
Tygr - Grande
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Pre-Tertiary
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Columbia Rive
of the Columb
MzPzm (metamo
undifferentia

GEOLOGIC
TRIMBLE (
& 1970).
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OTHBERG (

GEOLOGIC
HAMILL, K

BASE MAP
1:250,000

Tholeiitic basalt flows of the Saddle Mountains, Wanapum and Grande Ronde Formations. Locally includes talus, colluvium and thin loess deposits which overlie the basalt flows. Individual members are identified as follows:

Tysm - Saddle Mountain Basalt Formation (undifferentiated)
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Tygr - Grande Ronde Basalt Formation, (undifferentiated) Includes flow of N1, N2, R1 and R2 magnetic polarities.

pT

Pre-Tertiary

Pre-Tertiary rocks, undifferentiated (Precambrian through Mesozoic) metamorphic and plutonic rocks which are locally exposed below the Columbia River Basalt flows: includes TpCr (rocks older than basalt of the Columbia River Group) of Newcomb (1970); TMzg, (plutonic rocks), MzPzm (metamorphic rocks) Rockwell (1979); and pm (pre-Miocene rocks, undifferentiated) of Rigby and Othberg (1979).

NOTES

GEOLOGIC CONTACTS MODIFIED FROM GARD AND WALDRON (1954), TRIMBLE (1954), WALDRON AND GARD (1954 & 1955), NEWCOMB (1965 & 1970), MOLENAAR (1968), KIENLE AND NEWCOMB (1973), SWANSON AND OTHERS (1977 & 1979), KIENLE AND OTHERS (1979), RIGBY AND OTHBERG (1979) AND ROCKWELL (1979).

GEOLOGIC AND TECTONIC RECONNAISSANCE BY C.F. KIENLE, JR., M.L. HAMILL, K.E. LITE AND G.L. PETERSON.

BASE MAP FROM U.S. CORPS OF ENGINEERS, ARMY MAP SERVICE, 1:250,000 SCALE.

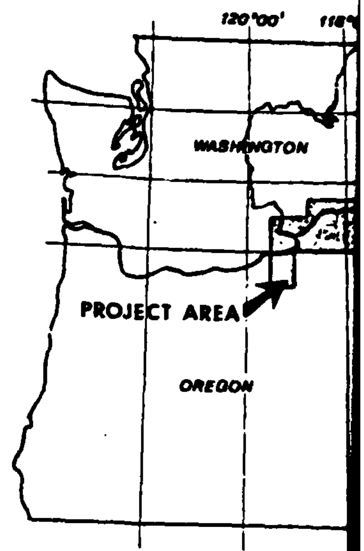
⊕ Horizontal bedding

10 Measured strike and di

3 Apparent strike and di

A A' Geologic cross-section

VICINITY MAP



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RECONNAISSANCE GEOLOGIC AND
OF THE HITE FAULT AND LO
RIVER CORRIDOR, WASHIN

SCALE 1:125,000	DRN M. KELLY
DATE NOV. 1980	CHK/APP C.E KIENLE

(14)

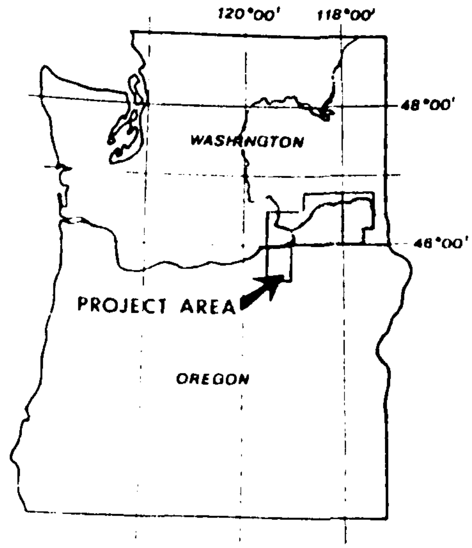
Horizontal bedding

Measured strike and dip

Apparent strike and dip

Geologic cross-section

VICINITY MAP



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RECONNAISSANCE GEOLOGIC AND TECTONIC MAP
OF THE HITE FAULT AND LOWER SNAKE
RIVER CORRIDOR, WASHINGTON

SCALE 1:125,000	DRN M. KELLY	NO. PLATE 3
DATE NOV 1980	CHK/APP C.F. KIENLE	SHEET

15